Velopharyngeal function and speech

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VELOPHARYNGEAL FUNCTION AND SPEECH

Stellingen

1 De afsluiting van de velopharyngeale opening komt tot stand door elevatie van het gehemelte en constrictie van de pharynxwand.

2 De musculus levator veli palatini heeft een dubbele innervatie via de plexus pharyngeus en de nervus facialis. De snelle willekeurige wisseling van de velopharyngeale opening tijdens het spreken wordt bestuurd door de nervus facialis (N VII).

3 Schedeldefecten bij kinderen, die voor operatieve behandeling in aanmerking komen, behoren te worden gesloten met autologe bottransplantaten; bij voorkeur vrije ribtransplantaten.

4 Primaire tangentiële excisie en vrije huidtransplantatie bij diepe tweedegraads brandwonden heeft de voorkeur boven een conservatieve behandeling en resulteert in een betere huidbedekking.

5 Vrije transplantatie van gedenerveerde spieren is een waardevolle bijdrage voor de behandeling van patienten met een facialis paralyse.

6 De opvatting, dat het middenoor een bevoorrechte plaats is voor transplantatie doeleinden is onjuist.

7 Persoonlijke observatie van de patient tijdens narcose kan niet worden vervangen door een monitor.

8 Fotografische documentatie is voor vele medische specialismen een onmisbaar onderdeel voor goede patientbegeleiding en vormt mede de basis voor de medische opleiding en de critische evaluatie van de behandelingsresultaten.

9 Zaken die medisch geheim dienen te blijven behoren alleen geregistreerd te zijn in het privé medisch archief van de betrokken specialist.

10 De doorlopende actieve dag- en nachtdiensten zoals nog gebruikelijk bij de opleiding van enkele heelkundige specialismen behoren tot een overleefd inwijdingsritueel en komt de patientenzorg niet ten goede.

11 De ontwikkeling van de industrie in de Eemshaven berust op de illusie van voortgaande productie groei en is dus te beschouwen als een verspilling van kapitaal en natuurlijke hulpbronnen.

Stellingen behorende bij J. W. Mulder, M.D.,
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RIJKSUNIVERSITEIT TE GRONINGEN

VELOPHARYNGEAL FUNCTION AND SPEECH

Electromyography, pharyngoscopy and speech analysis in subjects with normal speech, patients with rhinolalia aperta and patients treated with a pharyngeal flap.

PROEFSCHRIFT

ter verkrijging van het doctoraat in de geneeskunde
aan de Rijksuniversiteit te Groningen
op gezag van de Rector Magnificus Dr. M. J. Janssen
in het openbaar te verdedigen op woensdag 19 mei 1976
des namiddags te 4 uur door

JAN WIEBE MULDER

geboren te Palembang

VAN GORCUM & COMP. B.V. ASSEN/AMSTERDAM

PROMOTOREN:

PROF. DR. A. J. C. HUFFSTADT
DR. H. J. DE JONGH
CO-REFERENT:
R. W. PIGOTT, F.R.C.S.

Voorwoord

Gaarne wil ik allen dank zeggen, die op enigerlei wijze hebben medegewerkt aan de totstandkoming van dit proefschrift.

In de eerste plaats mijn moeder, die door haar kritische instelling naast goede zorg, de grondslag heeft gelegd voor mijn verdere ontwikkeling.

Mijn basis opleiding algemene heelkunde heb ik genoten onder de leiding van Prof. Dr. P. J. Kuijjer waarvoor ik hem oprechte dank betuig.

Prof. Dr. A. J. C. Huffstadt heeft mij opgeleid tot plastisch chirurg en reeds op de eerste dag van die opleiding de mogelijkheden tot dit onderzoek duidelijk aangegeven. De voortdurende belangstelling en daadwerkelijke hulp die ik gedurende de afgelopen jaren van hem heb ondervonden werkten stimulerend en hebben er toe bijgedragen dat dit proefschrift binnen redelijke tijd kon worden voltooid.

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Dr. H. J. de Jongh heeft mij ingewijd in de beginselen van het electromyografisch onderzoek. Door zijn belangstelling voor de klinische betekenis van het fundamenteel wetenschappelijke werk werd dit onderzoek mogelijk gemaakt in het laboratorium voor Anatomie en Embryologie te Groningen.

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Drs. D. H. E. Lichtendahl heeft op artistieke wijze de tekeningen en schema's verzorgd.

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Nel heeft mij altijd opgewekt geholpen met de uitwerking van de meetresultaten en daarbij het vele tikwerk verzorgd; wij hebben samen dit proefschrift voltooid.

Contents

Purpose of this study

1.1 Introduction

The formation of speech has always received much attention because speech is the most important means of human communication. The form and function of the laryngeal, oral and nasal pharynx contribute individually and in combination. When air is expired from the lungs, it passes the vocal cords. The tension of the vocal cords causes vibration in the air column above them and forms the tonality when the air passes freely into the open.
In the laryngeal pharynx the air flow can be stopped by the epiglottis. In the oral and nasal pharynx the air flow through the nasal cavities can be stopped by closing the entrance of the nasal cavities by the velopharyngeal mechanism. A competent velopharyngeal closing mechanism is essential for clear speech.
It should be realised that even in this period of technical and biomechanical knowledge the opinions on the way in which the velopharyngeal mechanism acts are still controversial.
Much of the available information on the velopharyngeal mechanism has been obtained by aerodynamic studies, air pressure measurements and acoustic analyses of speech.
During the last twenty years many cineradiographic studies have improved our understanding of this mechanism.
Direct observation of the velopharyngeal walls, as is possible in patients with facial defects following tumour surgery, has also contributed to an understanding of the velopharyngeal mechanism.
With newer and better technical facilities available, good and reliable transnasal pharyngoscopy has recently become possible.
Electromyography as a tool for direct measurement of the active components of the velopharyngeal mechanism has been used by a number of investigators.
Any research in which a combination of methods is used gives a better understanding of the velopharyngeal mechanism in normal and nasal speech. At the Department of Plastic Surgery of the State University Hospital Groningen, patients with nasal speech have always been

carefully studied to obtain information on normal function, insufficient function and the actual value and function of our method of treatment. The present study considers the velopharyngeal mechanism in subjects with normal speech and in patients with an incompetent mechanism resulting in nasal speech. Pharyngoscopy and electromyography were used for detailed recording of muscle function in the pharyngeal area. Speech itself was analysed by experienced speech therapists. Correlation of the results of these three methods will contribute to a better understanding of the very complex speech formation.

1.2 Problem statement

In recent years several electromyographic studies have been published Two carefully designed studies of velopharyngeal function were reported by Fritzell (1963, 1969). The electromyographic activity of the different components of this mechanism were analysed in 14 male and 12 female adults with normal speech. In a companion study Fritzell made simultaneous electromyographic and cineradiographic recordings which were synchronized; 13 normal speaking adults, 6 males and 7 females, were analysed. Recent developments in electromyographic technique and data recording made further investigation worthwhile.

Electromyographic recordings of patients with rhinolalia aperta are rare and have not been correlated with the degree of nasality of their speech.

Pigott (1969) introduced nasendoscopy as a useful tool of investigation and this method is now used by many others, (Champion, 1971; Boekhoff and Huffstadt, 1972; Miyazaki, 1975) but further detailed studies have not yet been published. The recent development of cineradiographic techniques makes an important contribution to our understanding of the velopharyngeal mechanism.

The present electromyographic and nasendoscopic study may give some support to the statements in recent articles on cineradiographic studies (Kelsey, 1972; Skolnick, 1972, 1973; Sphrintzen et al. 1974).

In planning this study, the following questions were raised:

1. How are the various activities of the velopharyngeal muscles related in subjects with normal speech?
2. What are the causes of velopharyngeal incompetence in patients with:
   a. congenital short palate
   b. cleft palate (with and without palatoraphy)?
3. How are the various velopharyngeal muscle activities related in patients with rhinolalia aperta?
4. a. How are the various velopharyngeal muscle activities related in patients with an inferiorly based pharyngeal flap?

b. Is the inferiorly based pharyngeal flap itself active?
5. Can activity of the velopharyngeal muscles be used as a predictor of speech improvement when operation is considered?

The present study has two parts:

1. electromyography of the velopharyngeal mechanism in subjects with normal speech.
2. electromyography, nasendoscopy and speech analysis in patients with rhinolalia aperta.

1.3 Nomenclature and terminology

For a better understanding of the terminology the following descriptions and definitions are given.

capacitance: a capacitator is a device consisting of two electrodes facing, but separated from, each other. The capacitance is directly proportional to the surface area of the two electrodes and inversely proportional to the distance between them. The capacitance is the power of an apparatus to store static electricity.

cineradiography: motion pictures of an X-ray study.

coupling gate: opening between two cavities; in this study used as the opening between the nasal and oral cavity.

integration of signals: the combination of signals in data which can be better described. During the study the electromyographic recordings were integrated, in which procedure the energy display by an electrode pair in a muscle is expressed in pulses on graph paper. These pulse numbers are more easily compared than the original electromyographic recordings.

palate: roof of the mouth, consisting of an anterior bony or hard palate and a posterior muscular or soft palate.

cleft palate: fissure of the palate as a result of a developmental disturbance.

submucous cleft palate: in this developmental disturbance no fusion of the muscular components of the palatal halves has taken place, although the mucous membrane is intact. Since the muscular components do not have their proper position, the function of the palate is impaired.

congenital short palate: in this developmental disturbance the controlled closure of the velopharyngeal port by movements of the palate is impaired, although the anatomical units of the velopharyngeal port as such seem to be intact. During the swallowing reflex there is complete closure of the velopharyngeal port, but during speech the controlled closure of the velopharyngeal port is insufficient.

palatoraphy: closure of a cleft palate or a submucous cleft palate, by which procedure the muscles of the palate and the nasal and oral mucosa are sutured in the midline. There are various methods of palatoplasty but in this study palatoraphy was always performed with the aid of relaxing incisions on the lateral side of each palatal shelve and detachment of the levator and palatopharyngeus muscles from the posterior edge of the hard palate. No so-called push back procedure was exercised.

pharyngeal flap: a muco-muscular bridge between the posterior pharyngeal wall and the posterior border of the soft palate. A pharyngeal flap formed at the same operation in which palatoraphy is carried out is called a primary pharyngeal flap. A pharyngeal flap formed during a separate operative procedure is called a secondary pharyngeal flap.
All pharyngeal flaps mentioned in this study are inferiorly (caudally) based, with the base of the flap approximately at the level of the soft palate at rest.

pharyngoscopy: direct visual observation of the pharyngeal area by a transoral or transnasal route. When a transnasal route is chosen, the use of an endoscope is necessary.

phonemes: sound elements of a language which can be used separately as tests. In the speech tests 'oral words' and 'nasal words' are used. In the production of 'oral words' the sounds are produced by an air flow largely through the oral cavity. In the production of 'nasal words' the sounds are produced by an air flow largely through the nasal cavities.

rhinolalia: nasal speech, with an abnormal passage of air through the nasal cavities during speech. There can be too much or too little air-flow, with too much air passing the nasal cavity during speech it is called rhinolalia aperta (hypernasality), with too little air passing the nasal cavity during speech it is called rhinolalia clausa (hyponasality). When the quantity of air passing the nasal cavity is too much for oral phonemes and too little for nasal phonemes the disorder is called rhinolalia mixta. The qualities of speech are best analysed by speech therapists, who also indicate when speech can be considered normal or abnormal.

ready position of the palate: when people are asked to produce test phonemes the palate moves into a position appropriate for the production of the required sound some time before the air flow passes the oral and nasal cavities and the sound is actually produced. The position of the palate in those situations is called the ready position.

sound spectrography: the technical procedure by which the varying energy produced during speech can be visualised and registered.

2. Current concepts of speech and velopharyngeal function

2.1 Review of the literature

In 1863 Passavant had already observed that 'the musculus constrictor pharyngeus superior is a muscle that serves speech'. He was aware of the constrictive activity of the velopharyngeal muscles in normal speech. Herman Gutzmann (1891) also realized the existence of this mechanism.

An attempt to give a complete list of studies performed, would do too little credit to many investigators who remain unmentioned. Historical surveys of that kind were briefly given by Saunders (1968), Fritzell (1969), Yules and Chase (1969), Dickson (1972), Sprietersbach (1973) and many others.

The present study confines itself to current concepts and methods used; they will be discussed in separate sections:

2.2 Current concepts of the velopharyngeal mechanism based on cineradiography

In the past 20 years several cineradiographic studies have been made. Cineradiography of the velopharyngeal region was usually done in a lateral projection only.

The movements of the soft palate during normal speech were analysed in detail by Björk and Nylen (1966), who used cineradiography synchronized with sound spectrography. They also made transverse tomograms during the production of different nasal sounds. Comparative tomographic and cineradiographic studies of velopharyngeal closure were carried out in 15 patients with a pharyngeal flap. The closing mechanism was found to follow the normal pattern in those patients who achieved normal speech.

Transverse tomographic studies in 10 normal persons showed the coupling gate (in mm^2) between oral and nasal cavity to be a simple linear function of its sagittal diameter (in mm). As a result, the coupling gate between the nasal and oral cavities can be easily measured on an X-ray cinefilm taken in a lateral projection.

In further studies by Björk and Nylen (1966) the same linear relation of the coupling gate (in mm^2) between oral and nasal cavity and the sagittal diameter (in mm) was found in 5 patients with a cranially based pharyngeal flap and normal speech. They also measured the relation between coupling gate (in mm^2) and sagittal diameter (in mm) in 4 people with normal speech and facial defects, in whom direct visual observation of the velopharyngeal mechanism was possible, with identical results.
Lateral radiography and lateral cineradiography became a standard method of evaluation of the velopharyngeal mechanism. Several authors reported having used this method in their evaluation of patients and other aspects of the velopharyngeal mechanism. Benson (1972), Bluestone (1972), Bzoch (1968), Carpenter (1968), Dickson (1969), Fritzell (1969), Van Gelder (1965), Gonzales (1970), Honig (1963), Lubker(1968), Massengill (1966), Sedláčková (1967), Subtelny (1970), Wada (1970), and many others.
Through these investigations the usual positions and movements of the soft palate, tongue and posterior pharyngeal wall, as seen in a lateral view, became generally known and accepted.
Some investigators were not satisfied with a lateral projection only, and various other projections with and without contrast medium were tried. Skolnick and McCall (1970, 1972, 1973, 1974) and Kuehn (1975) reported on extensive studies of the velopharyngeal mechanism in multiple projections; they stated that the lateral wall activity of the velopharyngeal port may vary but is certainly essential for a well-functioning mechanism. These films can be studied again and again and the results of this study are very convincing.
Some of the projections advocated by Skolnick (1974, 1975) and others are very uncomfortable for the patient and not physiological. It is not possible to achieve certain projections in every patient; for example the submentovertical projection is impossible if a patient is unable to bend his neck sufficiently.
Similar studies were reported by Kelsey (1972), who stated that lateral wall motion can be used as a predictor of surgical success. He observed his patients with velopharyngeal insufficiency in a prospective study before and after operation.
Zwitman et al. (1973) reported on routine submentovertical projections in their analysis of velopharyngeal dynamics.
Björk (1966) had already mentioned the active muscular constriction of the lateral portions of the velopharynx in patients with velopharyngeal imcompetence. He interpreted these activities without further comment as compensatory.

In the movements of the velopharyngeal closing mechanism the following components must be distinguished:

1. elevation and dorsal movement of the soft palate;
2. medial movement of the lateral pharyngeal walls;
3. ventral bulging of the posterior pharyngeal wall.

The elevation and dorsal movement of the soft palate obviously represents the most important contribution to closure. It can be very clearly demonstrated by radiography in a lateral projection and it accounts for the fact that many authors refer to pharyngeal closure as a valve function.

A medial movement of the lateral pharyngeal walls was shown to occur (by recent cineradiographic studies) in people with normal speech and in patients with rhinolalia aperta (Kelsey, 1972; Skolnick, 1973). The sphincter action of the lateral pharyngeal walls was convincingly demonstrated. The forward bulging of the posterior pharyngeal wall is normally minimal and can only occasionally contribute to the sphincter action of the velopharyngeal mechanism.

2.3 Current concepts of the velopharyngeal mechanism based on pharyngoscopy

Direct observation of the oral-nasal coupling gate gives the best information on its mechanism of action. Oral observation can be easily performed (Subtelny, 1970; Drost, 1972) but only in some of the sustained vowels and nasal consonants. Oral observation of the velopharyngeal mechanism is possible with a wide scope. The scope is introduced into the mouth and the patient closes his mouth tightly around the scope (Subtelny, 1970) or around a round piece of plexiglas (Drost, 1972). In this way the oral cavity can be closed and air pressure can build up, which is necessary for the production of oral consonants and connected speech. However, movements of the tongue are obstructed by the instrument and this examination cannot qualify as representative of a normal physiological condition.

The oral panendoscope described by Taub (1966) did not solve this technical problem either. Direct observation of the velopharyngeal mechanism through the nasal cavity is possible in patients with facial defects and has been used to correlate other methods of investigation such as cineradiography (Björk, 1966).

Reliable methods for direct visual observation of the velopharyngeal mechanism became available with the development of smaller and better optical instruments. Nasendoscopy was introduced as a routine method of pharyngeal examination by Pigott (1969). He used small (4.2 mm Ø) optical instruments which can be introduced through the nose and passed back to the nasal pharynx with little discomfort. All actions of the velopharyngeal mechanism (swallowing, breathing, sucking, blowing and speech) can be observed without interference. Pigott made his initial examinations with the subject supine. In two

separate articles, he described the nasendoscopic features of the normal palatopharyngeal valve in a group of 25 volunteers and the nasendoscopic features in a group of 23 surgically treated cleft palate patients with residual velopharyngeal incompetence.
ENT surgeons also use this method for direct viewing and documentation of nasal cavities (Herberhold, 1973; Buiter, 1974). Further detailed reports on this method of investigation in larger series of people with normal speech and patients with rhinolalia are not yet available.
Matsuya (1974) reported his findings on 7 individuals with normal speech. Champion (1971) discussed the nasendoscopic and photographic appearance of 15 patients with palatopharyngeal incompetence. Boekhoff and Huffstadt gave a preliminary report on a large series of 200 subjects with normal speech and 50 surgically treated cleft palate patients at the Copenhagen Cleft Palate Meeting (August 1972). In Pigott's thorough study by means of direct observation, the valve action of the soft palate and the constrictive action of the lateral and posterior pharyngeal walls were clearly shown both in subjects with normal speech and in patients with an incompetent velopharyngeal mechanism.

2.4 Current concepts of the velopharyngeal mechanism based on electromyography

In recent years several investigators have used electromyographic techniques. The application of useful techniques in speech research was surveyed and discussed by Fromkin and Ladefoged (1966).
Li and Lundervold (1958) reported on palatal muscle activity in 5 'normal' subjects and in 11 pre-and postoperative cleft palate patients. They used concentric needle electrodes with an oral approach and tested muscle activity during breathing, swallowing and phonating.
In a group of 18 cleft palate patients Broadbent and Swinyard (1959) tested the muscle activity of superiorly and inferiorly based pharyngeal flaps with monopolar needle electrodes and found them active during swallowing. They also tested the tensor, levator and constrictor muscle activity in a few patients.
Basmajian and Dutta (1964) used flexible bipolare wire electrodes in a study of 10 'normal' subjects. In an oral approach they tested the activity of the levator and constrictor superior, medius and inferior muscles during sucking and swallowing.
Böhme, Šram and Kalvadová (1966) reported on 10 'normal' subjects. They tested the tensor and levator palatini muscles in an oral approach with bipolar needle electrodes during breathing and some sustained vowels, and found a difference in onset, duration and degree of activity of levator and tensor muscles.

Chaco and Yules (1969) used concentric needle electrodes and an oral approach in a study of 42 cleft palate patients with a pharyngeal flap and 81 patients without cleft palate, but with an incompetent velopharyngeal mechanism after tonsillectomy-adenoidectomy. They tested the muscle activity of the levator and superior constrictor and, in the first group, the activity of the pharyngeal flap, during a sustained vowel */a:/*. The group of patients who did not benefit from the pharyngeal flap operation showed abnormal EMG patterns either from the flap or from the palatal muscles. In the group of patients which showed improvement of speech after the operation, all showed 'normal' EMG patterns. In the post-tonsillectomy-adenoidectomy group of 81 patients, 6 patients with a submucous cleft palate were detected by electromyography. In these 6 patients, no electromyographic signals were found in the median part of the palate.
Further studies by McCoy (1972); Owsley Jr. (1972) and Fára (1972) indicated different opinions. McCoy (1972) found the pharyngeal flap to be adynamic and proposed the use of a different kind of bipedicled flap. In a histological and electromyographic survey of 154 patients with a primary pharyngeal flap, Fára (1972) found muscle activity of the flap to be decreasing for 15 years after the operation. He performed electromyography of the pharyngeal flap during the vomiting reflex.
Lubker (1968) used suction cup electrodes in his studies of the activity of the soft palate during sustained vowels and nasal sounds in 5 individuals. He found a continually changing pattern of activity which was positively correlated with the velopharyngeal position.
Fritzell (1963, 1969) was the first to use the nasal approach in a careful study of the velopharyngeal muscles during connected speech. He used specially made needle electrodes for the tensor, levator and superior constrictor muscles which could be inserted through the nose. Using thin wire electrodes, he examined the palatoglossus and palatopharyngeal muscles. This method, he claimed, did not interfere with normal articulation and phonation. The levator muscle appears to have primary control over the position of the soft palate. The other muscles seem only to assist the levator or to modify slightly the gross pattern of velar movements as determined by the levator. An electromyographic study of the muscles of mastication and their correlation to facial morphology was performed by Møller (1966).
Sedláčková (1967, 1973) published some interesting reports on a combined electromyographic study of facial musculature, velopharyngeal musculature and their morphological relations to the innervation regions of the fifth, seventh and tenth cranial nerves. Her findings support the assumption of a double innervation of the levator veli palatini by the facial (N. VII) and the vagus (N.X) nerves.
These studies confirm those of Passavant (1863) and many others who had already described different mechanisms of closure of the velo-

pharyngeal port in speech and in swallowing. The facial nerve serves communication, which is a phylogenetically younger function; and the vagal system is involved in the phylogenetically older functions of ingestion and swallowing. Apart from Fritzell's report (1969) no intramuscular recording of the superior constrictor, levator, tensor, palatoglossus and palatopharyngeal muscles during different consonants, vowels and connected speech have yet been published. Many questions concerning the correlation of these muscle actions in subjects with normal speech and patients with an incompetent velopharyngeal closing mechanism have yet to be answered.

2.5 Current concepts of the velopharyngeal mechanism based on the use of other methods

Nasal and oral air flow measurements can be performed in many different ways together with speech recordings (Subtelny, 1969; Warren, 1969, 1975; Fletcher, 1970; Machida, 1970; Habal, 1974; and many others). Recently some new techniques have been introduced which make it possible to measure the relative distances of the different structures in the mouth during speech (Christiansen, 1971; Cole, 1971). With a device consisting of two electrodes opposite to, but separated from each other, it is possible to measure the distance between them. This device is called a capacitor. The 'capacitance' is directly proportional to the surface area of the two electrodes and inversely proportional to the inter-electrode distance. When surface area and capacitance are known, the distance between the electrodes may be obtained. The human body may serve as one side of a capacitance circuit (the ground side, due to its size and the high frequencies used in the operation of the circuit). If the 'hot' side of the capacitance circuit takes the form of a small aluminum foil disc embedded in acrylic and held in close proximity to the hard palate, but shielded from it, then the capacitance of the circuit will vary as the tongue, a moving grounded structure, approaches the aluminum disc. In this way, particularly the position of the tongue against the velum is traced, and earlier findings by cineradiographic methods may be confirmed.

2.6 Functional anatomy

When air is expired from the lungs, it passes the vocal cords. The tension of the vocal cords causes vibration in the air column above them and forms the tonality when the air passes freely into the open. The air flow can be stopped by closing the mouth or by the action of the epiglottis in the laryngeal pharynx.

Because of the form and function of the laryngeal, oral and nasal

pharynx the air flow can be transformed into intelligible speech. Each anatomical unit contributes by itself and also in combination with the others. In the oral and nasal pharynx the air flow through the nasal cavities can be stopped by closing the entrance of the nasal cavities via the velopharyngeal mechanism. The oral passage can be closed by the action of the tongue, lips and jaw. The vowels and the consonants are formed by the changing position of the tongue, jaw, lips, soft palate and pharyngeal walls. The continually changing positions of these structures result in articulate speech.
During the production of different sustained vowel sounds the soft palate rises in accordance to the position of the tongue from a low position for the low vowels, to a high position for the high vowels (Benson, 1972). In the latter position, complete or nearly complete closure of the velopharyngeal mechanism is found. The vowels referred to as phonemes are hereby given in the order from low to high: */a/*, */e/*, */o/*, */i/*, */y/* (fig. 1).

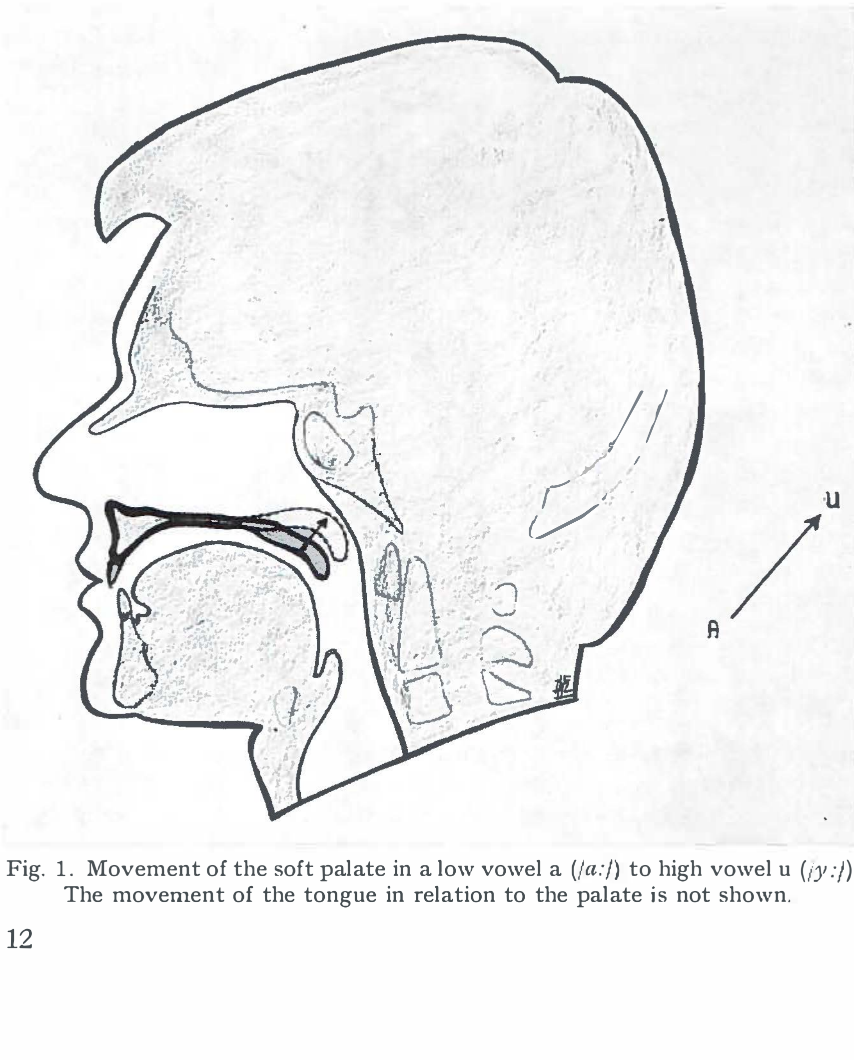


Fig. 1. Movement of the soft palate in a low vowel a (*/a:/*) to high vowel u (*/y:/*). The movement of the tongue in relation to the palate is not shown.

The consonants are differentiated into oral and nasal consonants. In the formation of the isolated nasal consonants the air flows through the nasal cavities, and the soft palate is in a low position. The oral consonants can be differentiated into plosives and fricatives. In these consonants the complete flow of air goes through the oral cavity, and complete closure of the velopharyngeal mechanism is necessary. The different consonants are formed by a specific position of tongue, jaw and lips together. In the plosives, the oral air flow is stopped by closure of the oral cavity. The air pressure increases. When the air pressure is sufficient for the required sound, the mouth is opened to let the air burst out of the oral cavity, set in the particular position for the plosive required. The plosives expressed in the phonemes /*p*/, /*d*/ and /*k*/ were tested. During the production of fricatives there is a continuous air flow through the oral cavity, set in the particular position for the fricative required. The fricative tested in this study is /*s*/. During speech the mobility of the oropharyngeal structures is essential. It occurs that the mobility of these structures is sufficient to produce a sustained vowel or an isolated consonant, but may be insufficient for connected speech. The value of velopharyngeal closure during swallowing, sucking and vomiting is evident. The complexity of speech formation clearly indicates that speech disorders may have various and combined causes.

2.6.1 Anatomy in subjects with normal speech

Different opinions still exist about details of the form and structures of the velopharyngeal mechanism in subjects with normal speech. The following survey of the palatopharyngeal muscles and their assumed functions is a condensed review of recent reports.

The musculus constrictor pharyngeus superior

This structure constitutes the muscular coat of the upper pharynx. Four parts can usually be distinguished:
- pars pterygopharyngea, attached to the lower half of the medial pterygoid plate and hamulus;
- pars buccopharyngea, attached to the pterygomandibular raphe;
- pars mylopharyngea, attached posteriorly to the inside of the mandible (the linea mylohyoidea);
- pars glossopharyngea, attached to the tongue.

These muscles join in the midline of the posterior pharyngeal wall at the pharyngeal raphe, which is fixed to the pharyngeal tuberculum of the occipital bone (cf. Hafferl, 1957).
The innervation is provided by the pharyngeal plexus, to which the glossopharyngeal and vagus nerves contribute branches. The blood

supply to the whole pharynx comes from the ascending pharyngeal and superior thyroid arteries.

When the superior constrictor contracts, the upper pharynx is narrowed by a medial movement of the lateral pharyngeal walls and forward bulging of the posterior pharyngeal wall. This forward movement of the posterior pharyngeal wall sometimes produces a transverse fold called the 'Passavant ridge', (Calnan 1957).

The musculus palatopharyngeus

This muscle originates on the inside of the superior constrictor on both sides, taking a longitudinal course to the posterior pharyngeal wall. These fibres converge from either side to the aponeurosis of the posterior border of the soft palate.

Another group of longitudinally (craniocaudally) arranged muscle fibres runs into the tip of the medial cartilaginous wall of the Eustachian tube and is called the salpingopharyngeus muscle. The mucomuscular fold formed by the palatopharyngeus is called arcus palatopharyngeus. The mucomuscular fold of the salpingopharyngeus is called plica salpingopharyngea. The palatopharyngeus and the salpingopharyngeus produce an upward movement of the pharyngeal walls when contraction takes place. The free posterior border of the soft palate is moved down and posteriorly by the action of the palatopharyngeus. The palatopharyngeus and superior constrictor muscles are closely related, as indicated by Whillis (1930) when he introduced the term 'palatopharyngeal sphincter'.

Townshend (1940) gave the following description, 'the fibres of the superior constrictor and the palatopharyngeus muscles are often so hopelessly entangled in the human subject that it is impossible to say where one muscle begins and the other ends'. The innervation is provided by the pharyngeal plexus. At contraction of the palatopharyngeus the soft palate is moved in a dorso-caudal direction, the lateral pharyngeal walls are moved medially and the posterior pharyngeal wall is moved forward and upward.

The musculus palatoglossus

This muscle originates from transverse fibres within the tongue and ascends to the lateral aspects of the palatal aponeurosis on each side. The mucomuscular fold formed by the palatoglossus in turn forms the arcus palatoglossus. The fossa tonsillaris lies between the arcus palatoglossus and the arcus palatopharyngeus. The innervation is provided by the pharyngeal plexus. When the palatoglossus contracts, the palate is lowered. It acts as an antagonist to the levator veli palatini (Van Gelder, 1965, Fritzell, 1969).

The musculus uvulae

This is a paired muscle which takes a longitudinal (ventro-dorsal) course beneath the nasal mucosa of the soft palate. It originates from the posterior part of the hard palate on both sides and runs to the tip of the uvula. The innervation is probably provided by the pharyngeal plexus (cf. Hafferl, 1957) but might also come from the lesser palatine nerve branches of the facial nerve (Broomhead, 1951). When the uvular muscle contracts, the uvula is shortened. This muscle has probably little or no significance in speech.

The musculus tensor veli palatini

This is a flat triangular muscle, with its base along the antero-lateral membranous wall of the Eustachian tube and its apex at the pterygoid hamulus on each side. Other fibres arise from the greater wing of the sphenoid bone immediately in front of and lateral to the spheno-petrosal fissure to which the auditory tube is attached and from the scaphoid fossa of the pterygoid process (cf. Brescia, 1971). Its tendon coils around the hamulus in a deep notch on its lateral side and spreads horizontally or slightly upwards, forming the aponeurosis of the soft palate.
The innervation is provided by the mandibular branch of the trigeminal nerve. When the tensor veli palatini contracts the aponeurosis palatini is pulled tight. The anterior lateral membranous wall of the Eustachian tube is moved forward and the tube opens, so that the air pressure between the middle ear and pharynx is equalized. The contribution of this muscle action to speech is doubtful (Fritzell, 1969). Its activity is strongest at the time of deglutition and swallowing (Whillis, 1930) and the action of the tensor is synchronized and coördinated with that of the levator and other muscle groups.

The musculus levator veli palatini

This muscle arises from the petrosal bone on both sides in front of the carotid canal and descends in ventro-medial direction along the posterior and inferior border of the Eustachian tube. It ends in the middle third of the palatal aponeurosis. The innervation of the levator veli palatini is still a controversial subject. According to many investigators the levator veli palatini is innervated by branches of the pharyngeal plexus (Gray's Anatomy, 1967; Hafferl, 1957). Sedlačková (1967, 1973), Podvinec (1952) and other investigators however, pointed to the more complex innervation of the levator veli palatini by the facial nerve (N.VII). The assumption that the levator veli palatini is innervated by the nucleus of the facial nerve via the greater superficial petrosal and sphenopalatine ganglion was already held by Erb a hundred years ago, (cf. Sedláčková, 1967).

Other investigators (Podvinec, 1952; Sedláčková, 1967, 1973) confirmed these findings but found a dual innervation of the levator veli palatini: during speech by the facial nerve (N.VI) and during swallowing by the vagus nerve (N.X) through the pharyngeal plexus. When the levator contracts, the medial portion of the soft palate is moved up and back. The levator can change the position of the soft palate to a considerable extent. There is disagreement about its action on the Eustachian tube. Some authors state that its action can narrow the entrance of the tube (Van Gelder, 1965) while many others do not connect its action to the opening of the tube (Fritzell, 1969; Brescia, 1971, and others). Kriens (1970) demonstrated the opening of the tube by levator action.
The soft palate receives most of its circulation from the palatine arteries and veins. The palatine arteries originate from the maxillary arteries.
The combined and changing action of all these muscles is essential in speech formation. Diagrams of the function of the muscular com-

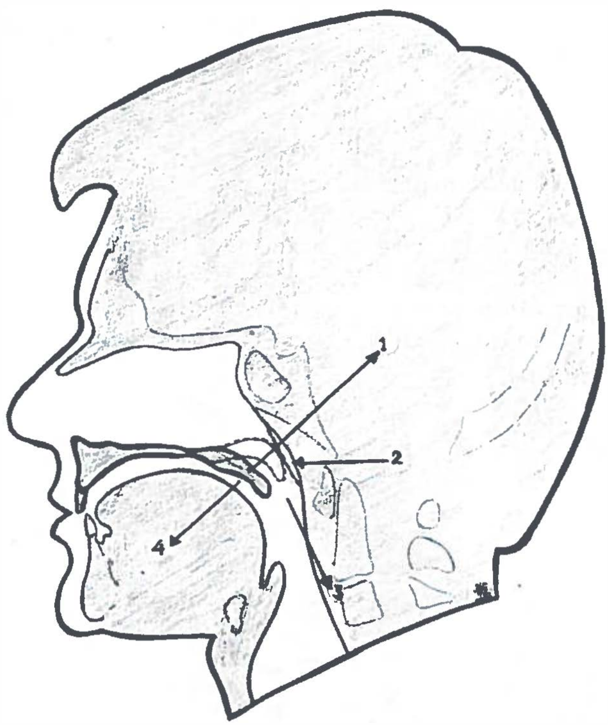


Fig. 2. Sagittal section

ponents of the velopharyngeal mechanism have been given by a number of authors (Whillis, 1930; Braithwaite, 1964; Fritzell, 1969; Kriens, 1970; Dickson, 1972, 1975; and many others).
A diagram of the direction of movement of the soft palate by the muscular components of the velopharyngeal mechanism is given in a sagittal and in a horizontal section at the approximate level of the soft palate (fig. 2, fig. 3).

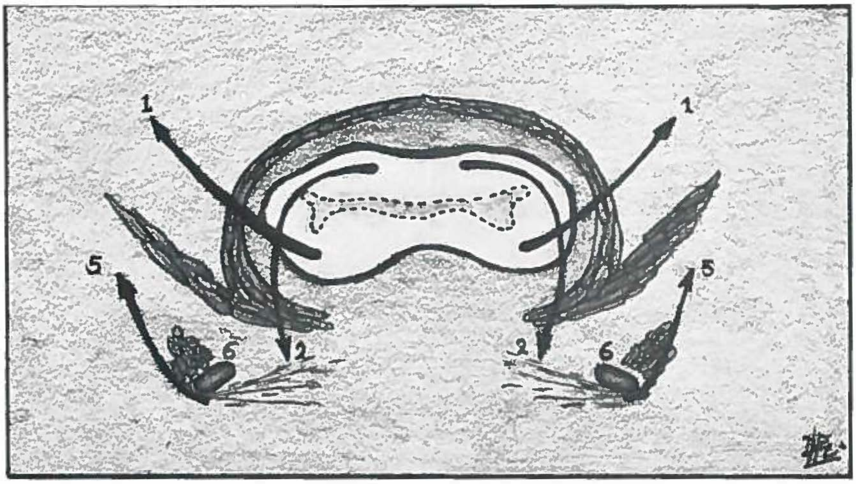


Fig. 3. Horizontal section. 1. Levator veli palatini. 2. Constrictor pharyngeus superior. 3. Palatopharyngeus. 4. Palatoglossus. 5. Tensor veli palatini. 6. Hamulus Pterygoïdens.

2.6.2 Anatomy in patients with rhinolalia aperta

2.6.2.1 Cleft palate

The lip and palate may fail to differentiate at critical points and critical times in the developing foetus. If differentiation of the tissues which comprise these structures is incomplete or abnormal, formation of the lip and palate can be defective in varying degrees: the defect may be incomplete, complete, unilateral or bilateral (Brescia, 1971).
Both types of palatal cleft (the complete unilateral cleft and the median cleft of the palate) show the same anatomical deformity of the muscular components of the velopharyngeal mechanism. A detailed study of this anatomical deformity has recently been published by Kriens (1970, 1975).
The vascular patterns in normal and cleft palate human embryos were extensively studied by Frederiks (1972). When no fusion of the palatal shelves takes place, the palatal muscles are attached to the palatal aponeurosis and the posterior border of the hard palate. There is no

backward traction on the palatal aponeurosis by the muscle slings of levator and palatopharyngeus muscles (Kriens, 1970). The palatopharyngeus and levator veli palatini with this lack of backward traction were already clearly described by Veau (1931) and are therefor called 'Veau's cleft muscle'. When palatoraphy is performed, it is

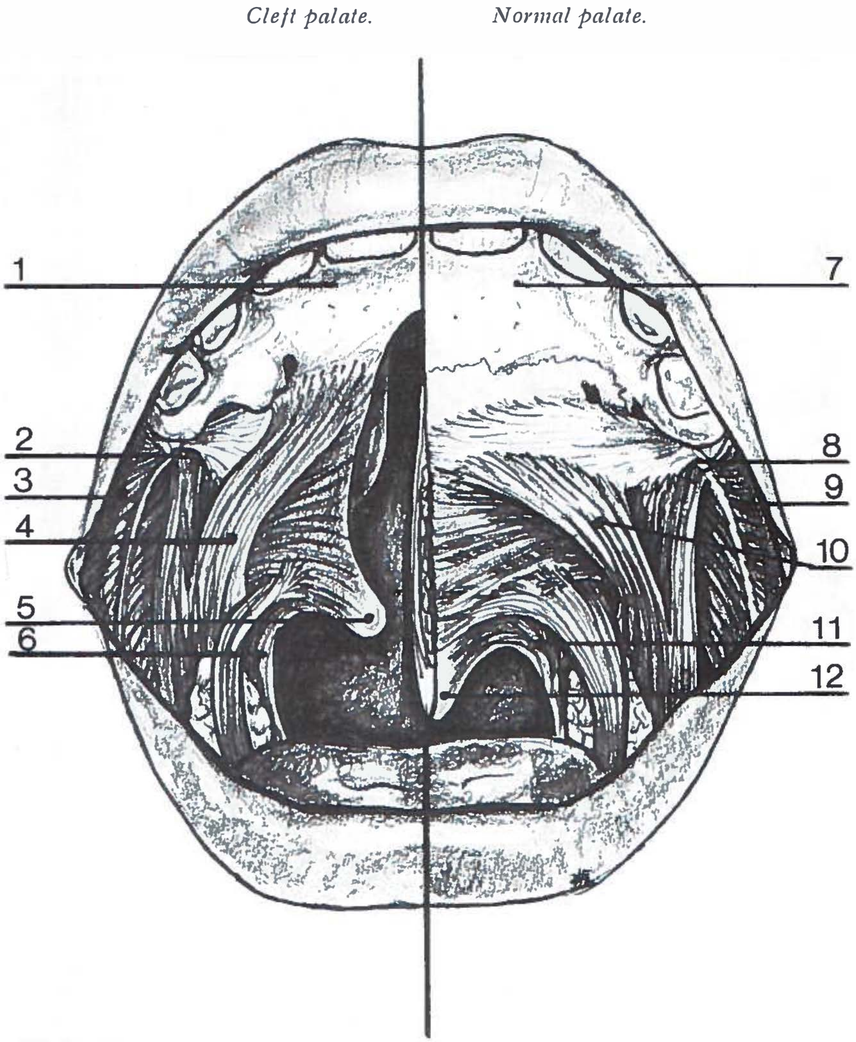


Fig. 4. Anatomy of normal and cleft palate.

1. Hard palate. 2. Hamulus pterygoideus. 3. M. tensor veli palatini. 4. M. levator veli palatini. 5. Uvula. 6. M. palatopharyngeus.

7. Hard palate. 8. Hamulus pterygoideus. 9. M. tensor veli palatini. 10. M. levator veli palatini. 11. M. palatopharyngeus. 12. Uvula.

essential that these muscles (palatopharyngeus and levator) are freed from the posterior border of the hard palate (the nasal spine) in order to restore the muscle slings of palatopharyngeus and levator. Braithwaite (1964) attributes the posterior movement of the soft palate to a combined action of the levator veli palatini and palatopharyngeus. The tensor veli palatini in the cleft palate condition has no firm attachment because the aponeurosis palatini is not held in balance, and therefore its action on the opening of the Eustachian tube is severely impaired. Palatoraphy gives improved tube function (Bluestone, 1972; Soudijn, 1972, 1975 (fig. 4).

2.6.2.2 Congenital short palate

'The congenitally short palate is that developmental disturbance of the palatal growth in which, although the valve membrane is intact, and there is function of the commanding muscles, the patient is not capable of controlled closure of the velar valve mechanism in speech'. This definition of the 'congenital short palate' was proposed by Winters (1967). In this definition the soft palate is considered as a valve membrane, although it has a complex tendinous and muscular structure. In a patient with a congenital short palate one often finds a short palate with little anatomical deformity. The disturbance can be heard in nasality during speech, due to an insufficient velopharyngeal closing mechanism, while during swallowing and sucking normal closure is effected. Sedláčková (1967) examined patients with a congenital short palate by palpation of the contracted muscle and radiocinematographic techniques. She stated that the velar hypoplasia found in congenital short palate is associated with hypoplasia of the facial musculature and narrowing of all facial orifices, giving the patient a typical appearance. The function of the velum is impaired, causing hyper-rhinolalia during phonation, while the velum is raised in a normal pattern when the patient swallows.

From the dissociation of the two basic functions of the velum, i.e. phonation and swallowing, a double innervation of the velum could be assumed. In her further studies (1973) by electromyographic techniques using monopolar needle electrodes, she found further evidence that the lesion in the congenital short palate syndrome is situated near the second branchial arch (occasionally near the first).

3. The present study

This study was carried out at the Department of Plastic Surgery and the Department of Anatomy and Embryology, State University, Groningen. The procedures used were developed in order to avoid interference with articulation as much as possible and to ensure that the subject of the experiment would feel at ease.
Pharyngoscopy as a routine procedure was introduced in our department some years ago, after a most helpful course of instruction by Pigott. It has since been used on hundreds of subjects with normal speech and patients with an incompetent velopharyngeal closing mechanism. In the development of our electromyographic techniques, 30 individuals were examined in various ways until technique and method were agreed upon.

3.1 Material

3.1.1 Subjects with normal speech

The first group in the experiment was the group of subjects with normal speech. None of the individuals in this group had ever heard any comments on nasal quality of their speech, which was accepted as normal within the common variations of dialect. None of the individuals in this group had any neurological or muscular disease or anatomical abnormality in the velopharyngeal mechanism. In this control group, 30 electromyographic recordings were obtained from 29 individuals. The subjects were volunteers, mostly medical students, but also some patients from the ward of the Plastic Surgery Department. There were 27 men and 2 women, ranging in age from 22 to 41 years (average 25). There were only 6 men who had not been operated on their tonsils or adenoids. None of the 23 who had had an adenoidectomy and/or tonsillectomy had any speech impairment as a result of that operation.

3.1.2 Patients with rhinolalia aperta

Twenty one patients were examined before as well as 3 months after operation. Ten other patients had been operated on between 1 to 7 years before. On these patients 52 experiments were performed.

All individuals were submitted to speech analysis, pharyngoscopic examination and electromyography. The details of these 3 examinations will be discussed in separate sections.

The group of 21 patients, who were examined before and after operation had the following disorders:

a. congenital short palate: 10 patients (5 boys and 5 girls) all of whom had been previously subjected to adenoidectomy and tonsillectomy.
b. cheilo-gnato-palatoschisis; 8 patients with a cleft of lip and palate which involved one or both sides: 4 males and 4 females. Three males had previously had a successful palatoraphy.
c. palatoschisis mediana; 2 patients with a cleft of the palate who had previously had a palatoraphy: 2 female patients.
d. submucous cleft palate; 1 patient in whom no fusion of the musculature of the two palatal shelves had occurred: 1 female patient.

The patients with a congenital short palate ranged in age from 9 to 15 years (average 12). In all these patients pharyngoplasty with an inferiorly based flap was performed in order to improve speech. The other 11 patients ranged in age from 9 to 52 years (average 33). Four of these patients had previously been submitted to a successful complete palate repair, but with residual rhinolalia aperta. In these 4 patients an inferiorly based pharyngeal flap was used.

The other 7 patients were submitted to posterior palatoraphy and a primary inferiorly based pharyngeal flap was used in the same operation. One of these was the patient with the submucous cleft palate. The other 6 patients had used a palatal obturator until the operation was performed. They were either dissatisfied with their prosthesis, or the condition of their teeth precluded continued use.

The group of 10 patients who were examined 1 to 7 years (average 4 years) after operation had been submitted to pharyngoplasty with an inferiorly based pharyngeal flap. These 10 patients had the following disorders:

a. congenital short palate: 2 females and 2 males; only one of these patients, a male teacher, had not had an adenoidectomy and tonsillectomy.
b. unilateral or bilateral cheilo-gnato-palatoschisis: 1 male and 2 females.
c. palatoschisis mediana: 1 male and 1 female
d. submucous cleft palate: 1 female.

These 10 patients ranged in age from 15 to 73 years (average 29), but with an irregular pattern.

3.2 *Methods*

2.2.1 *Pharyngoscopy*

Nasendoscopy has been described by Pigott, 1969, 1974; Champion, 1971 and others). Pigott performed it with the subject in a recumbent or semi-recumbent position. In this position the effect of gravity on the soft palate is different from that in the usual upright position. The term nasal pharyngoscopy was introduced at our hospital in 1971 (Huffstadt) because we are specifically interested in the coupling gate of nasal and oral pharynx and not so much in the appearance of the nasal cavities. We therefore perform pharyngoscopy with the subject in an upright position. The head is not fixed in position, because fixation might play a role in the velopharyngeal closing mechanism (McWilliams, 1968). We have tried various types of pharyngoscope but currently we most often use straight scopes with an angle of 0° and 30° at the tip and an external diameter of 4 mm. These scopes have a detachable fibre optic cable which can be fixed to the light source. The scopes can be attached firmly to a normal single-eye reflex camera. Th flashbulb unit is situated at the proximal end of the straight scope and is powered by a separate unit. The scope is introduced in the nostril through a hollow metal tube with an external diameter of 5 mm. In this way the tip of the scope remains free of mucus when entering the nasal pharynx. We have used other types of scope with angles of 60° and 70°, but found these less satisfactory in inspection of the velopharyngeal mechanism in plosives and during connected speech. Too little can be seen of the posterior pharyngeal walls with these types of scope. In infants we sometimes use scopes of 3.2 mm and 3.5 mm external diameter. These scopes are adequate for routine inspection but too narrow for photographic documentation. We use normal positive and negative colour films with speeds ranging from 50 ASA to 100 ASA. These films are processed in the normal way. The final print of these films can be enlarged if necessary.
We clean our scopes regularly with chlorohexidine.
We have used several types of topical anaesthetic, but we find cocaïne flakes the most useful and convenient. Using cotton wool tips, the flakes are introduced into the nasal cavity and the nasal pharynx through both nostrils. After a few minutes we introduce the pharyngoscope into the nostril which was most readily anaesthesized. We also perform pharyngoscopy on children, the youngest so far being 6 years old (fig. 5). We are not in favor of pharyngoscopy under sedation.
The pharyngoscopic findings are discussed in the following order:

1. Orientation within the nasal pharynx at rest.
2. Mobility of the structures of the nasal pharynx in subjects with a competent velopharyngeal mechanism.

3. Mobility of the structures of the nasal pharynx in patients with an incompetent velopharyngeal mechanism due to:
   a. cleft palate
   b. congenital short palate.
4. Mobility of the structures of the nasal pharynx in patients treated with a pharyngeal flap.

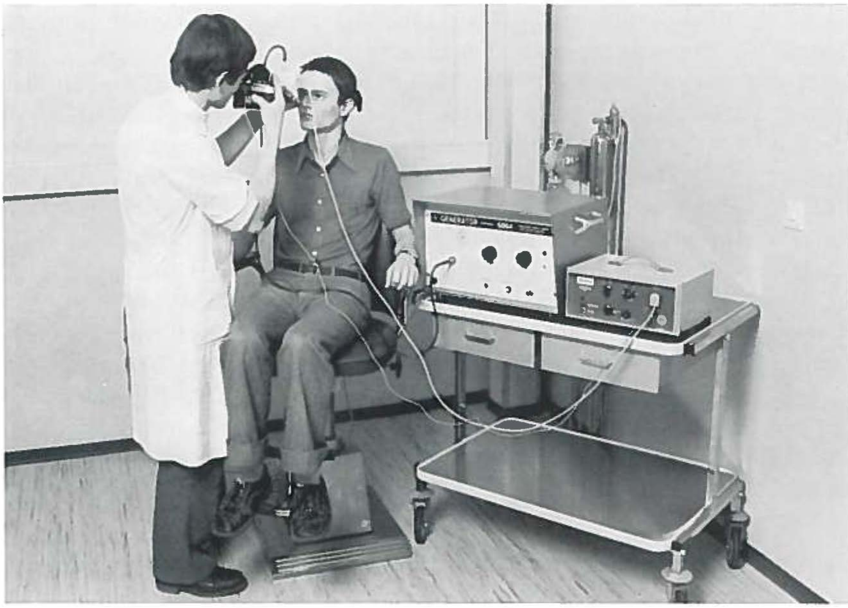


Fig. 5. Pharyngoscopy being performed.

Orientation within the nasal pharynx at rest

With the straight (0°) pharyngoscope in situ and the velopharyngeal mechanism at rest, the following structures can be recognized (as shown on the photograph with corresponding drawing (fig. 6). The posterior pharyngeal wall is situated in the centre of the photograph. In some individuals adenoid tissue can be seen. This tissue bleeds easily when touched by the scope. Scar tissue can be seen in adenoidectomized subjects. Some forward bulging of the posterior pharyngeal wall is usually seen at the velopharyngeal closure level. The lateral pharyngeal wall on both sides has a longitudinal mucomuscular fold called the plica salpingopharyngea. This fold is formed by the salpingopharyngeus muscle, which is a part of the constrictor pharyngeus superior. The fissure between the plica salpingopharyngea and the posterior pharyngeal wall is called Rosenmüller's fossa. The opening of the Eustachian tube is easily seen anterior of the plica salpingo-

pharyngea. The sloping structure from the entrance of the Eustachian tube to the soft palate is the levator eminence formed by the levator veli palatini muscle. Adjacent to this area on the lateral side runs the tensor veli palatini muscle from the anterior and lateral border of the cartilaginous wall of the Eustachian tube. The posterior border of the soft palate and its relation to the velopharyngeal port can be observed without difficulty. In some control individuals there is a bulging area in the middle of the soft palate which contains the uvular muscle. When the scope is carefully withdrawn, the posterior border of the nasal septum can be seen. On the lateral side the dorsal end of the inferior turbinate is readily visible.
The use of scopes with different angles at the tip facilitates orientation inside the pharyngeal cavities. The area where the velopharyngeal walls close can usually best be seen with the 0° (straight) and 30° downward aiming scope. The scope with a tip at a 70° angle gives a good view of the oropharynx and epiglottis at rest, and sometimes the vocal cords can be seen. During swallowing and during the production of oral consonants the movements of the palate are usually so marked that the palate is pushed against the tip of the scope and the point of contact of palate and posterior pharyngeal wall is obscured. Due to this way of introducing the scopes through a left or right nostril the aspect of the left and right pharyngeal walls are not symmetrical.

Mobility of the structures of the nasal pharynx in subjects with a competent velopharyngeal mechanism.

The pharyngoscopic view can only be documented properly when a stable position of the velopharyngeal port is secured. Photographs are routinely taken:
- at rest (fig. 7)
- at the closing phase of the velopharyngeal port in swallowing (fig. 8)
- during production of a sustained vowel */a:/* (fig. 9)
- during production of a sustained nasal sound (*m:/* (fig. 10)
- during production of a sustained fricative sound */s:/* (fig. 11)

Complete closure of the velopharyngeal port occurs in subjects with a competent velopharyngeal mechanism during speech.
Further information on the movements of the pharyngeal walls is obtained by pharyngoscopy during speech. The usual variation between consonants and vowels can be observed. In swallowing there is complete closure of the velopharyngeal port. There is a large lateral wall movement to the midline and marked elevation of the soft palate. In many subjects with normal speech an anterior movement of the posterior pharyngeal wall can be seen. During production of */a:/*, the palate usually shows moderate elevation and there is a slight medial

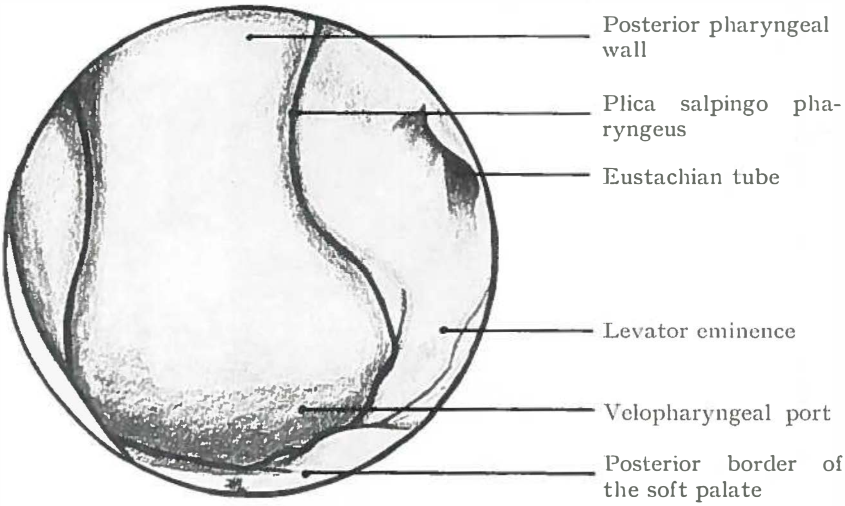


Fig. 6. Orientation in nasal pharynx at rest. Scope introduced in left nostril in subject with normal speech.

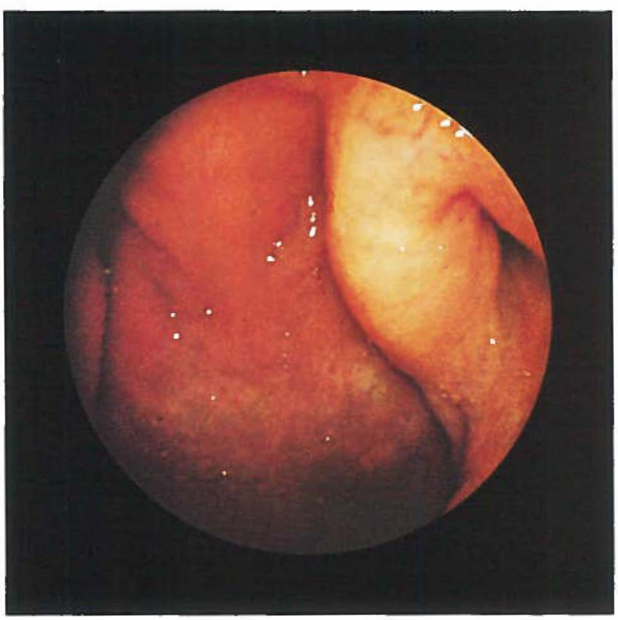


Fig. 7 at rest.

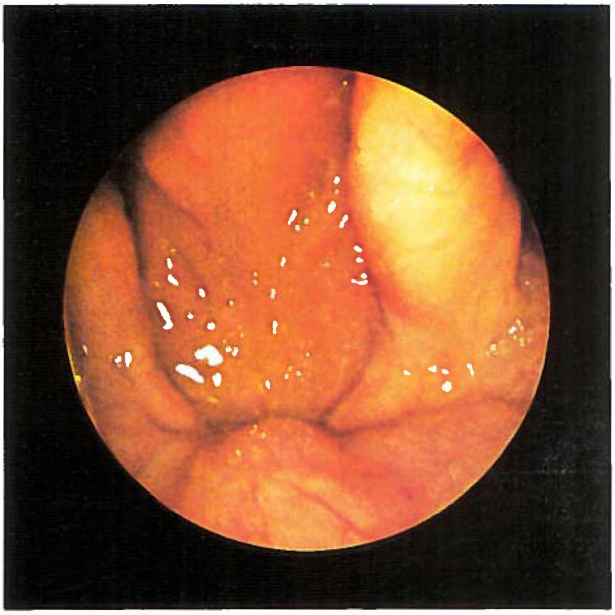


fig. 8 in swallowing

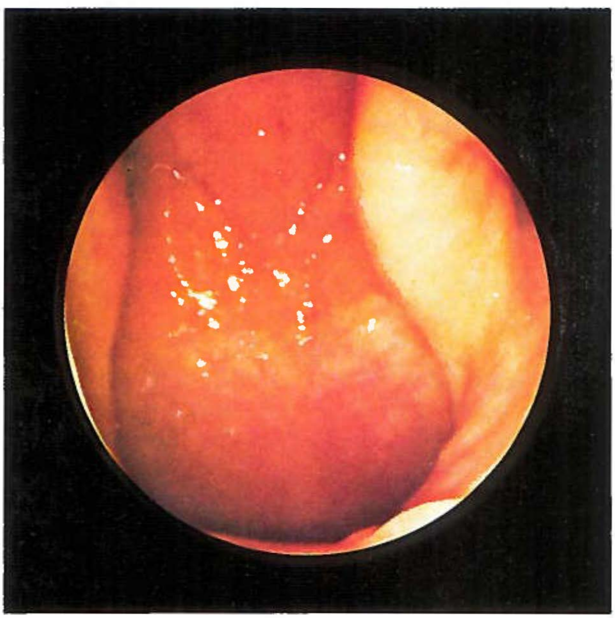


fig. 9 during production of /a:/

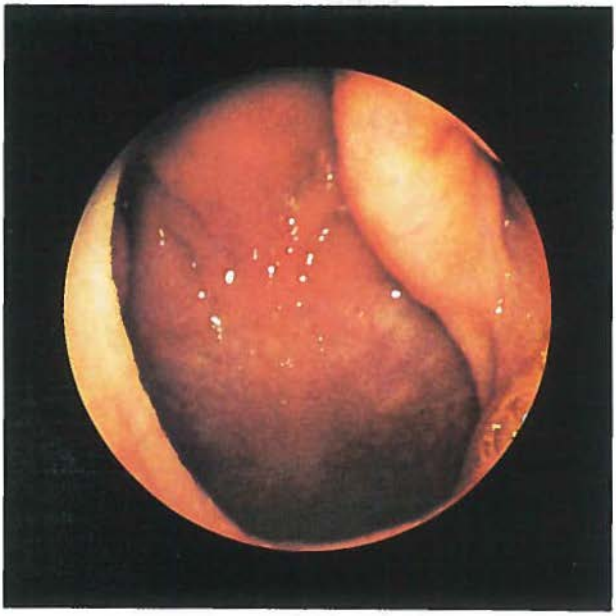


fig. 10 during production of /m:/

fig. 11 during production of /s:/

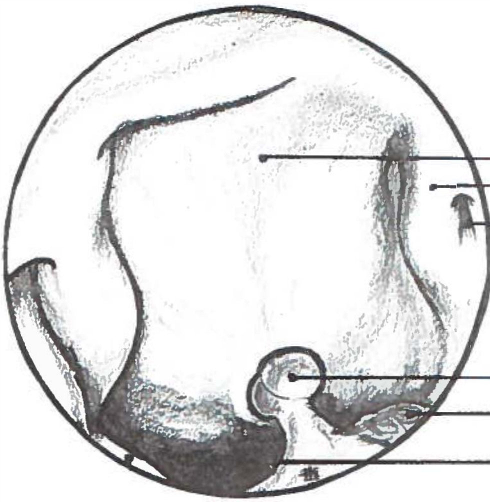


Fig. 12. Orientation in nasal pharynx at rest. Scope introduced in right nostril in patient with a pharyngeal flap.

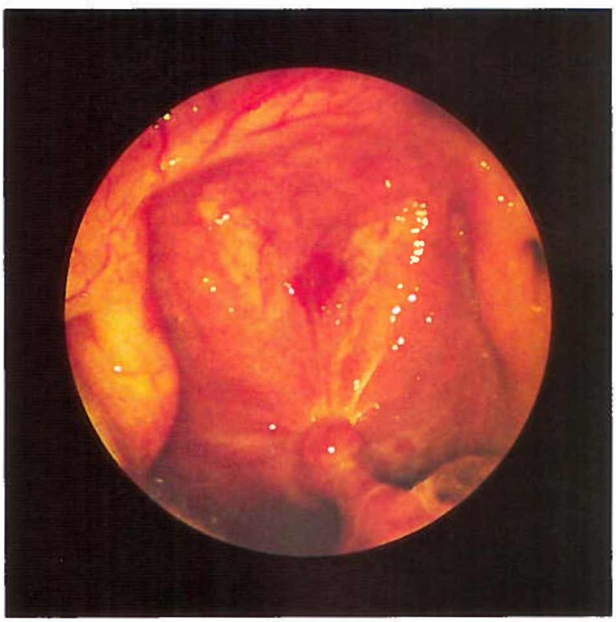


fig. 13 at rest

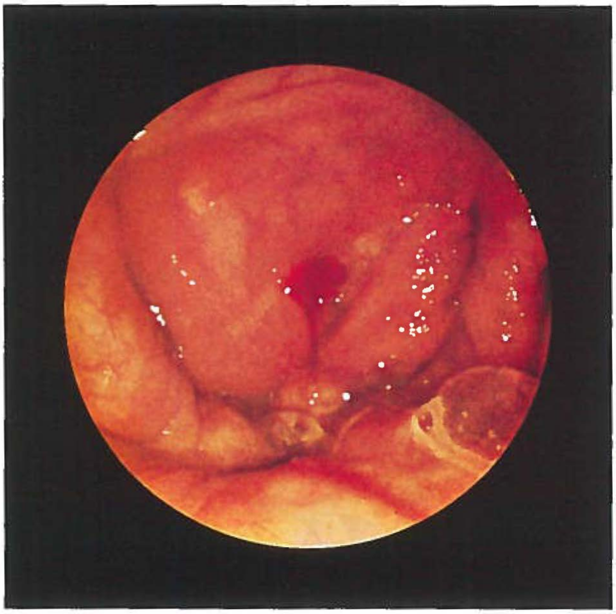


fig. 14 in swallowing

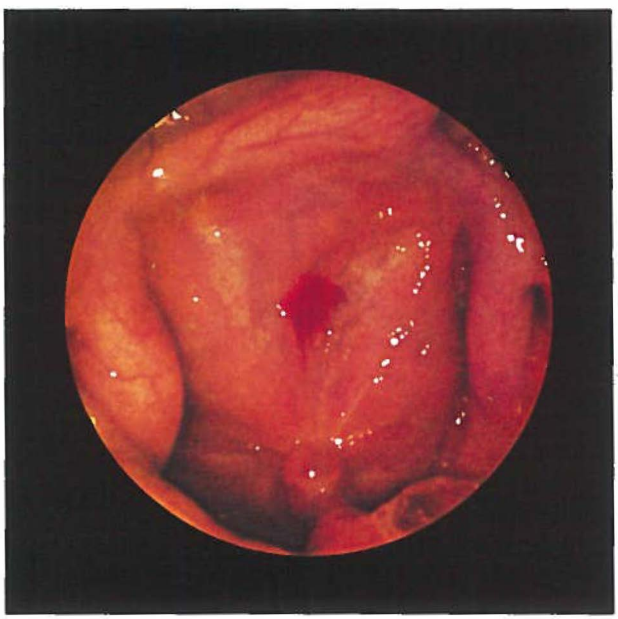


fig. 15 during production of /a:/

fig. 16 during production of /m:/

fig. 17 during production of /s:/

movement of the lateral pharyngeal walls. There is no movement of the posterior pharyngeal wall. During production of */m:/* the velopharyngeal port is wide open with the soft palate in a low position. The velopharyngeal porthole is open wider than when at rest. The lateral walls and posterior pharyngeal walls show no significant displacement. During production of */s:/* there is complete closure of the velopharyngeal port with high elevation of the palate and marked medial displacement of the lateral pharyngeal walls. In many people there is some forward movement of the posterior pharyngeal wall.
The amplitudes of the palatal movements are large during speech with rapid variation of vowels, plosives and nasal sounds. The posterior pharyngeal wall shows some forward movement and in some people a transverse mucosal fold can be seen, as already described by Passavant (1863).
The lateral walls usually show some activity, but far less than during production of a sustained fricative */s:/*. In a small number of subjects with a competent mechanism there seems to be more constrictive activity of the lateral walls during continued speech than usual, as also described by other authors (Skolnick et al. 1970, 1972, 1973).
Our findings do not quite confirm those of Pigott (1969, 1974). We did not see any significance of the uvula in the velopharyngeal closure mechanism. We examined our subjects in a physiological upright position. Pigott decribed his experiments with the subjects in a recumbent or semi-recumbent position. The effect of gravity on the soft palate plays a role in both positions.

Mobility of the structures of the nasal pharynx in patients with an incompetent velopharyngeal mechanism due to:
- untreated cleft palate
- congenital short palate.

Cleft palate

In patients with a cleft palate the freely moving borders of the two palatal shelves can be clearly seen and there is a wide view into the oropharynx down to the laryngopharynx. In these patients the vocal cords are readily visible. Most of these patients used obturators attached to dental prostheses which proved to be unsatisfactory in the long run when the condition of the teeth deteriorated. The movements of the posterior and lateral pharyngeal walls in these patients are usually gross, but closure can never be achieved during speech and seldom during swallowing. The two palatal shelves are retracted sideways and posteriorly by the action of the levator veli palatini muscles. These patients were treated by palatoraphy combined with a primary pharyngeal flap. Most of the cleft palate patients treated by palatoraphy only, achieve a competent velopharyngeal mechanism.

Cleft palate patients who do not achieve a competent velopharyngeal mechanism are treated in addition with a pharyngeal flap. In this group of patients nasal pharyngoscopy was performed before and 3 months after the pharyngeal flap operation. The cause of the velopharyngeal incompetence can be easily recognized in most patients. The soft palate is usually too short and not sufficiently mobile. The area of contact between soft palate and posterior and lateral pharyngeal walls is too small and adequate closure is not accomplished during production of speech. In some patients closure is not even accomplished during swallowing. The movements themselves of the soft palate, posterior- and lateral pharyngeal walls are similar to those in the controls. In some of these patients the gross movements of the posterior and lateral pharyngeal walls are shown. The lack of closure during speech was registered during production of the sustained fricative /s:/ and during swallowing (table 1).

Table 1 Table of movements of the structures of the velopharyngeal mechanism. The movements are graded in 4 grades: —, +, ++ and +++
velum = movements of soft palate
p.ph.w. = movement of posterior pharyngeal wall
lat.ph.w. = movement of lateral pharyngeal walls
phon. = phonation, closure during sustained fricative S, yes or no
swall. = swallowing, closure during swallowing, yes or no.

The same patient, investigated in two experiments, one before operation and one experiment after operation is listed in the same order.

I. Cleft palate patients, without palate repair

		before operation			
exp.	velum	p.ph.w.	lat.ph.w.	phon.	swall
62	++	+	+++	no	no
64	++	—	++	no	no
76	+	—	++	no	no
77	+	—	++	no	yes
79	++	++	++	no	yes
78	++	++	++	no	yes
		after operation			
88	+	—	+++	no	yes
100	++	—	+	no	yes
106	+	—	+	yes	yes
107	++	—	+	no	yes
110	+	—	+	yes	yes
108	++	+	+	no	yes
90	++	—	++	no	yes
92	++	—	++	yes	yes

II Cleft palate patients with palate repair and one patient with a submucous cleft palate

exp.	velum	p.ph.w.	lat.ph.w.	phon.	swall.
before operation					
53	++	+	++	no	no
56	++	+	++	no	yes
65	++	+	+	no	yes
72	+	++	++	no	yes
73	+	+	+++	no	yes
after operation					
82	++	—	++	yes	yes
85	++	—	++	no	yes
99	++	+	++	yes	yes
101	++	+	++	no	yes
105	+	—	+	no	yes
91	+++	—	++	yes	yes
94	++	+	++	yes	yes
97	+	—	+	no	yes
98	++	—	+	no	yes

III Patients with a congenital short palate

exp.	velum	p.ph.w.	lat.ph.w.	phon.	swall.
before operation					
52	+	—	++	no	yes
54	++	—	++	no	yes
57	+	—	+	no	yes
58	+	—	+	no	yes
59	+	—	+	no	yes
60	++	—	++	no	yes
66	++	—	++	yes	yes
74	++	+	++	no	yes
75	+	—	++	no	yes
80	++	—	++	no	yes
after operation					
81	++	—	++	yes	yes
83	++	—	++	yes	yes
84	++	—	+	no	yes
87	++	+	++	yes	yes
86	++	—	++	yes	yes
89	++	—	++	yes	yes
102	++	—	++	yes	yes
103	++	—	++	no	yes
104	++	+	++	yes	yes
109	+++	+	++	yes	yes
45	+	—	++	yes	yes
93	++	—	+	no	yes
95	+	+	++	no	yes
96	++	+	++	no	yes

Congenital short palate

In patients with this condition the anatomical structures seem to be intact, although the soft palate may appear short. Complete closure of the velopharyngeal port was easily achieved during swallowing in all patients of this group. The movements of the soft palate, backward displacement and elevation, are smaller than those in most of the subjects with normal speech. The movements of the posterior and lateral pharyngeal walls follow the same pattern as those in the subjects with normal speech. In some of the patients in this group the more pronounced movements of the lateral pharyngeal walls seem to compensate partly for the lack of velar elevation. During production of the sustained fricative */s:/*, complete velopharyngeal closure can usually be achieved, but in production of continued speech the incompetence of the velopharyngeal closing mechanism can be seen and heard. The movements of the soft palate, in relation to the movements of the posterior and lateral pharyngeal walls, are too slow to achieve adequate closure. In a separate table the movements of the velopharyngeal structures are shown. It should be realized, however, that a certain lack of co-ordination and speed in these movements is not registered (table 1).

Mobility of the structures of the nasal pharynx in patients treated with a pharyngeal flap.

The pharyngeal flap divides the velopharyngeal port. The two remaining portholes on both sides between the flap and the lateral pharyngeal walls are clearly seen. The following structures can be recognized, as shown on the photograph and corresponding drawing (fig. 12, 13).

The scope is introduced through the right nostril. The posterior pharyngeal wall and relatively small pharyngeal flap in this patient can clearly be seen. The right velopharyngeal porthole lies in front and the left velopharyngeal porthole is seen on the other side of the pharyngeal flap with a mucus bubble in front. At the base of the pharyngeal flap on the posterior pharyngeal wall, the scarred donor area can be seen. The lateral pharyngeal walls show the plica salpingopharyngea on both sides with the opening of the Eustachian tube. Rosenmüller's fossa between the plica salpingopharyngea and the posterior pharyngeal wall is visible on both sides. A small part of the levator eminence on the right side of the patient can be seen in front of the Eustachian tube. In swallowing, complete closure of the velopharyngeal port is accomplished in all patients. The medial displacement of the lateral pharyngeal walls and the posterior and upward displacement of the soft palate are clearly seen on the photograph (fig. 14). During production of the vowel */a:/* the palate shows moderate elevation and there is a slight medial movement of the

lateral pharyngeal walls. On the photograph only the right velopharyngeal port is seen; the left velopharyngeal port has a similar opening (fig. 15). During production of /s:/ complete closure should be achieved, as the patient shows on the photograph (fig. 17). Complete closure of the remaining portholes beside the pharyngeal flap is achieved by movement of the soft palate and the posterior and especially the lateral pharyngeal walls. A number of patients who show complete velopharyngeal closure during production of the sustained fricative /s:/ have an inadequate velopharyngeal mechanism in the production of continued speech. In these patients the soft palate and the lateral pharyngeal walls show lack of co-ordination and speed.
The relative movements of the velopharyngeal structures are shown in a separate table (1).

3.2.2 Electromyography

An outline of the instrumentation used in this study is shown in fig. 18 and a block diagram fig. 18a.
Electrodes. We prefer the oral approach for insertion of the electrodes under direct vision and for easy manipulation of the electrodes. We tried several kinds of intramuscular bipolar electrodes. The bipolar

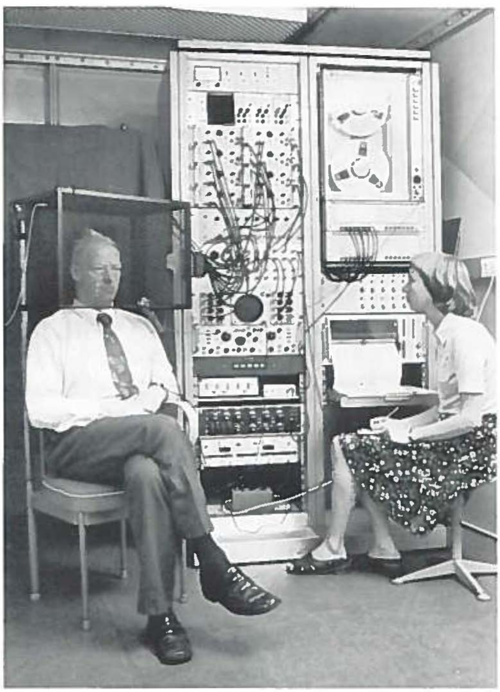


Fig. 18. Patient and electromyographic instruments with technical assistent.

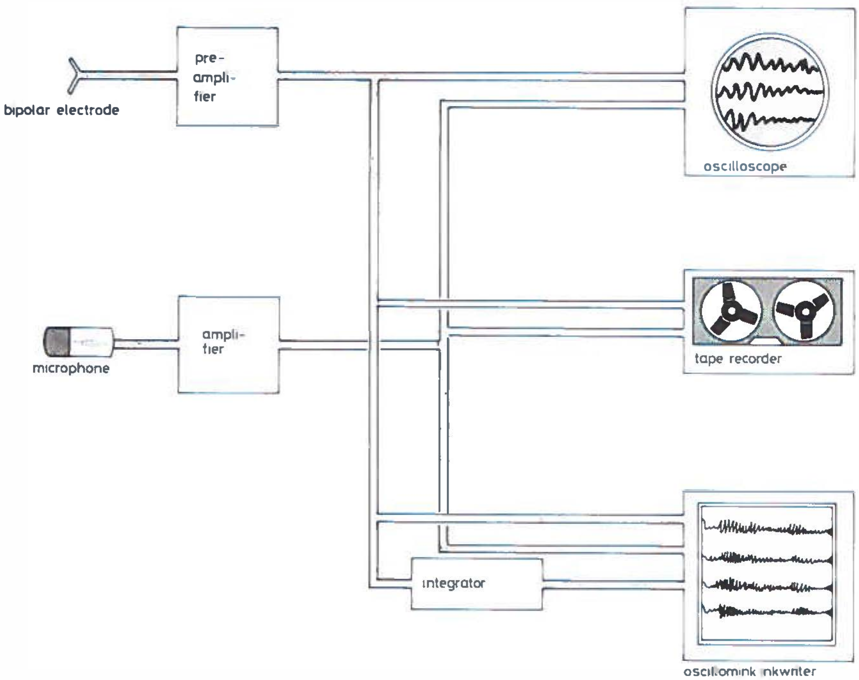


Fig. 18a Block diagram of instrumentation

needle electrode is the best because the distance between the two electrodes can be fixed accurately. These needle electrodes, however, can not be used in the moving structures of the mouth during connected speech. We therefore prefer bipolar wire electrodes which consist of insulated 0.05 mm (diameter) copper wires with hooked bare ends. These were introduced into the muscles by means of hypodermic needles, which were then withdrawn. This technique is a modification of that developed by Basmajian and Stecko (1962). These copper electrodes pick up signals from an area within approximately 1.5 mm from the bare tip ends, as established in animal experiments at the Laboratory of Anatomy, State University, Groningen. The copper of the electrodes does not cause demonstrable histological changes in the tissues. The electrodes can be pulled out easily at the end of the experiment and do not break during the experiment. The electrode wires move freely in the mouth and do not interfere with articulation. They are usually bundled together and leave the mouth at the right corner (fig. 19, 20).
Instruments. The electromyographic apparatus used in this study consists of 8 Princeton Applied Research Model 113 differential

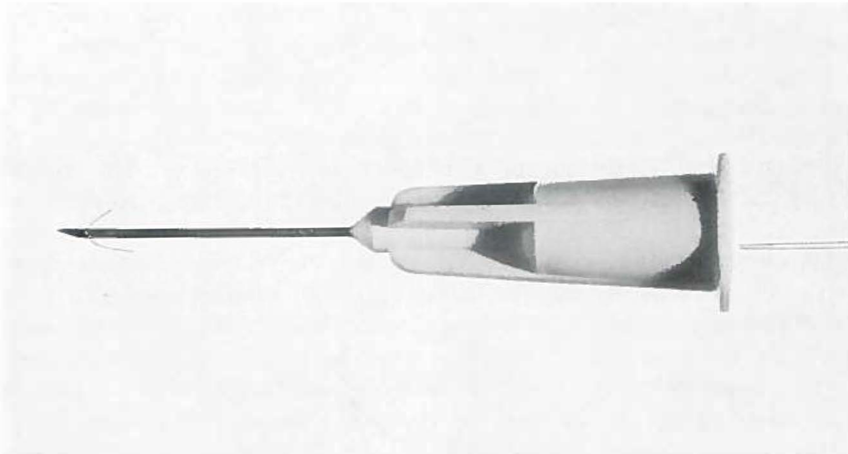


Fig. 19. Electrodes with hypodermic needle prior to insertion.

Fig. 20. Electrodes in situ in palate and pharyngeal wall of subject with normal speech.

amplifiers, whose output was recorded on a C.E.C. V.R. 3360 14-track tape recorder and on a Siemens Oscillomink B ink-writing chart recorder. The recorded signal can be checked on an 8-channel dual beam oscilloscope. Amplification of the electromyographic signals was kept constant for each recorded display during one experiment.

The electromyographic signals were integrated separately for quantitative comparison of the activities in the different muscle leads. This integration circuit has recently been developed at the Department of Anatomy and Embryology, University of Groningen. The energy display of the different electrodes is given in vertical lines on a horizontal line which runs parallel to the electromyographic spike recording. This energy display is more realistic than a rectified and averaged envelope, because the height of the spikes in a recorded electromyographic signal is only a momentary reflection of the number of motor units active, and the high spikes may be too far apart in time to reflect accurately the quantity of energy displayed. The number of integrated spikes can be counted in a period of time and these figures may be compared. An example of electromyographic signals and integrated signals is given (fig. 21). Together with the electromyographic signals the sound is recorded through a normal microphone.

Procedure. Before inserting the electrodes, the mouth and posterior pharyngeal wall are anaesthesized with a topical anaesthetic spray (xylocaine spray 8%). The electrodes can than be inserted with the aid of disposable hypodermic needles. In adults 7 electrodes were usually placed in the following order:

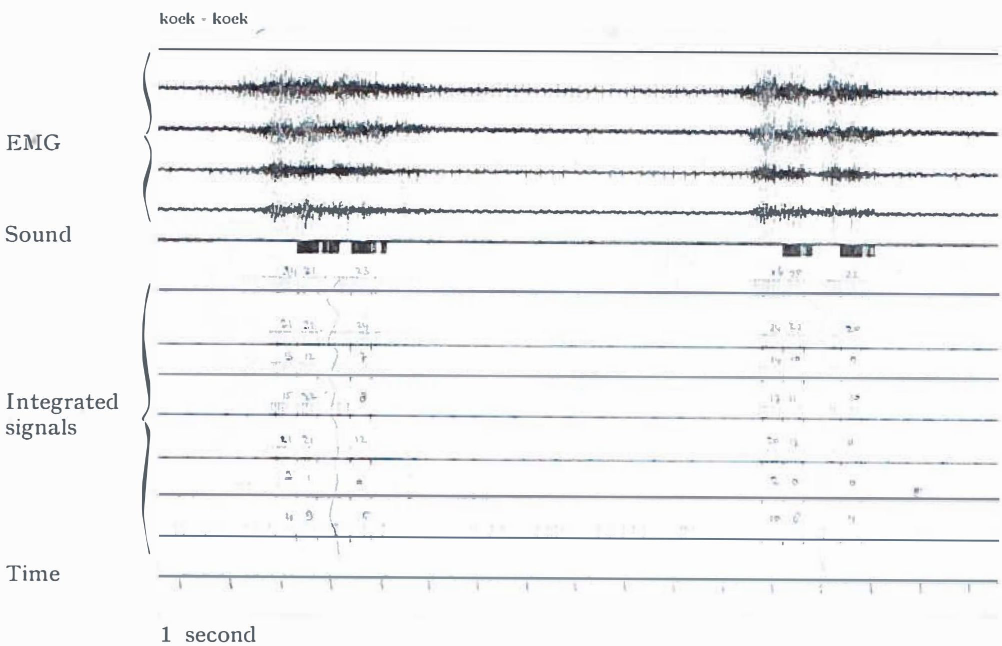


Fig. 21. Electromyographic signals and integrated signals in koekkoek

– levator veli palatini right side: the electrode is placed in the levator dimple in the soft palate while the subject says /*a:*/;
– palatoglossus right side: the electrode is placed in the muscular part of the arcus palatoglossus;
– levator veli palatini left side: identical to the right side;
– palatoglossus left side: identical to the right side;
– constrictor pharyngeus superior right side: the electrode is placed in a lateral direction on the posterior pharyngeal wall at the level of the oro-nasal coupling gate;
– constrictor pharyngeus superior left side: identical to the right side;
– tensor veli palatini right side: the electrode is inserted into the lateral side of the soft palate in an upward dorsal direction (fig. 22).

The palatopharyngeus instead of the palatoglossus was examined in seven controls with normal speech. The tensor veli palatini was measured on both sides in a preliminary series of the study but was

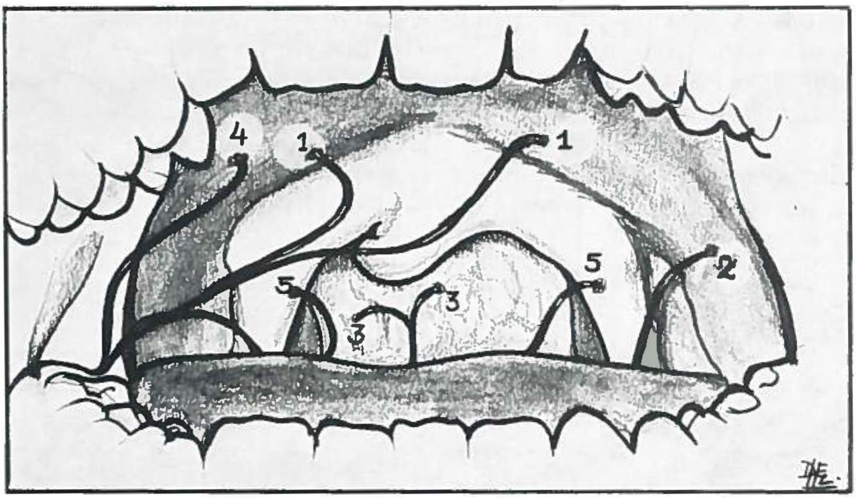


Fig. 22. Schematic representation of the position of the electrodes. 1. levator veli palatini. 2. palatoglossus. 3. constrictur pharyngeus superior. 4. tensor veli palatini. 5. palatopharyngeus.

found to have no specific relation to speech, as already mentioned by other investigators (Fritzell, 1969). In patients who had been submitted to a pharyngoplasty the activity of the flap was measured instead of the activity of the tensor veli palatini on the right side. In children we made only electromyographic recordings of the levator veli palatini and constrictor pharyngeus superior on both sides, and of the pharyngeal flap if present. We were able to make reliable electromyographic recordings in subjects aged 9 years and older.

In some of the younger children the electrodes could be introduced reasonably well but the programme of isolated phonemes and connected speech to be tested was not performed satisfactorily. We excluded these electromyographic recordings from our series. All subjects, controls as well as patients, performed the same series of isolated phonemes and connected speech; these will be discussed separately. The average time for electromyographic examination of the velopharyngeal muscles was approximately one hour.
The following muscles of the velopharyngeal mechanism were studied in the course of the experiments:
- levator veli palatini,
- constrictor pharyngeus superior,
- palatoglossus,
- palatopharyngeus,
- tensor veli palatini.

The levator veli palatini and the constrictor pharyngeus superior on both sides were measured in all experiments (82). In all postoperative patients the pharyngeal flap was studied (31 experiments). In 22 subjects with normal speech the activity of the palatoglossus was measured on both sides. In 7 subjects with normal speech the activity of the palatopharyngeus was measured on both sides. In all subjects with normal speech the activity of the tensor veli palatini was measured on the right side. In some of the patients the activity of the palato-

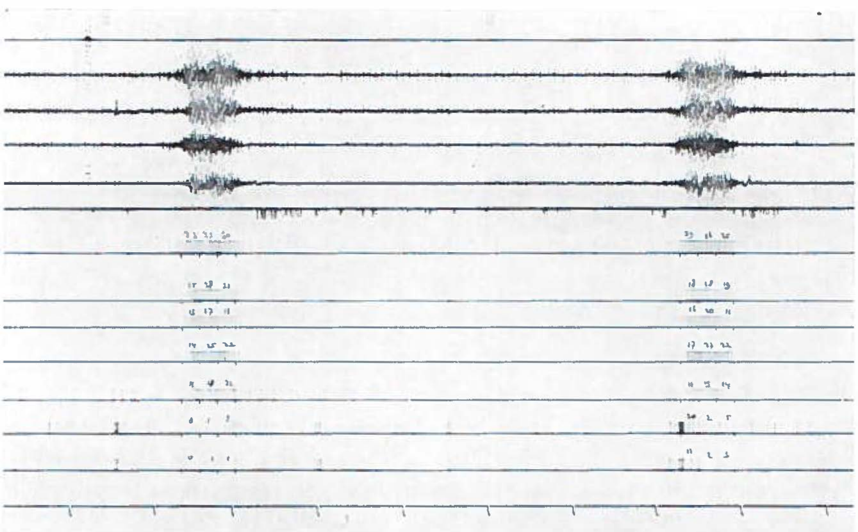


Fig. 23. Electromyographic signals and integration during swallowing.

glossus on both sides and of the tensor veli palatini on the right side was measured.

Recording programme. At the beginning and at the end of each experiment the activity of the muscles involved was measured during swallowing (fig. 23). Some photographs of the electromyographic recordings and integrated signals are given. The following phonemes and speech samples were chosen, expressed in phonetic signs and the Dutch equivalent respectively:

A.

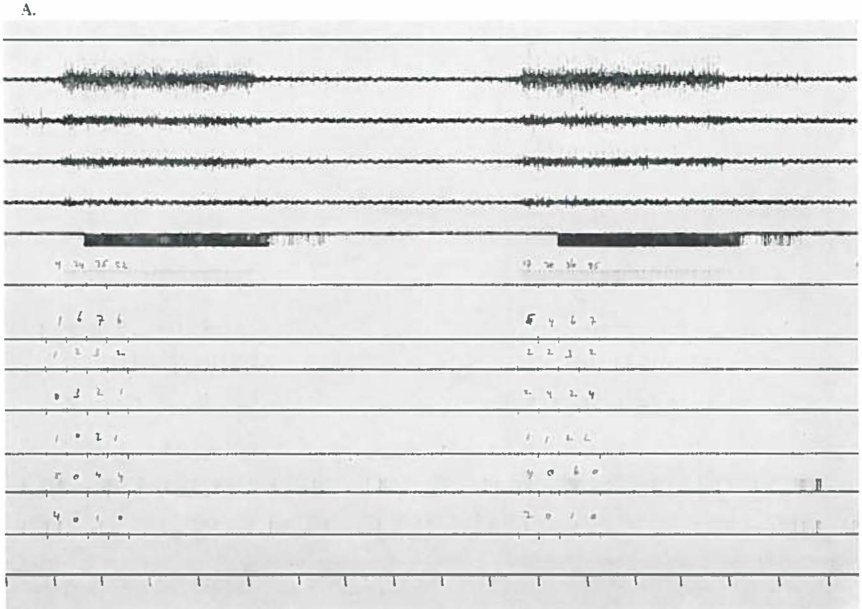


Fig. 24. during */a:/*

isolated sustained vowels: */a:/* (a), */e:/* (*e*), */i:/* (*i*), */o:/* (*o*) and */y:/* (*u*) (fig. 24).

oral consonants followed by a vowel (plosives): */pe/* (*pee*), */de/* (*dee*) and */ka/* (*ka*) (fig. 25).

nasal consonants preceded by a vowel: */εm/* (*em*), and */εn/* (*en*) (fig. 26).

speech: */kukkuk/* (*koekkoek*), */pit/* (*piet*), */pus/* (*poes*), */iŋε/* (*inge*) */da na: m* van *iŋə/* (de naam van inge). (fig. 27).

All subjects carried out this complete programme, each part of it being repeated 3 times. The electromyographic signals were integrated separately in order to make a quantitative comparison of the energy display during the production of the different phonemes and speech samples. In the isolated vowel and consonant tests, energy displays

K - a

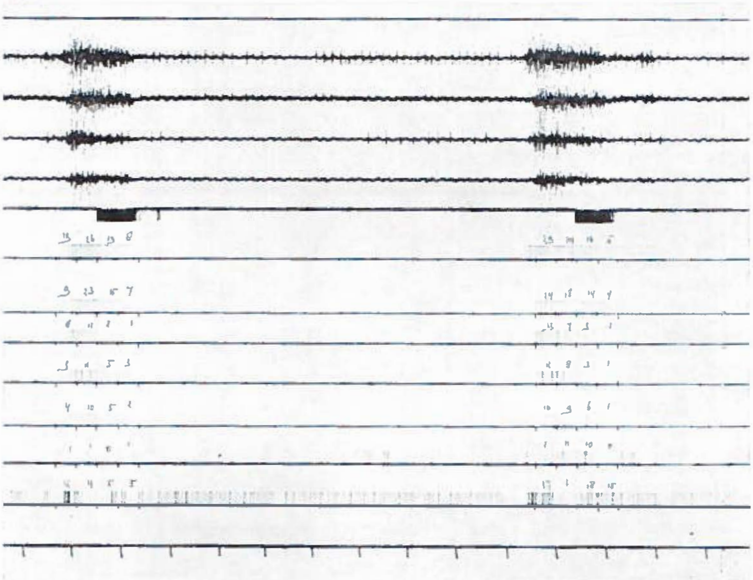


Fig. 25. during /*ka:*/

e m

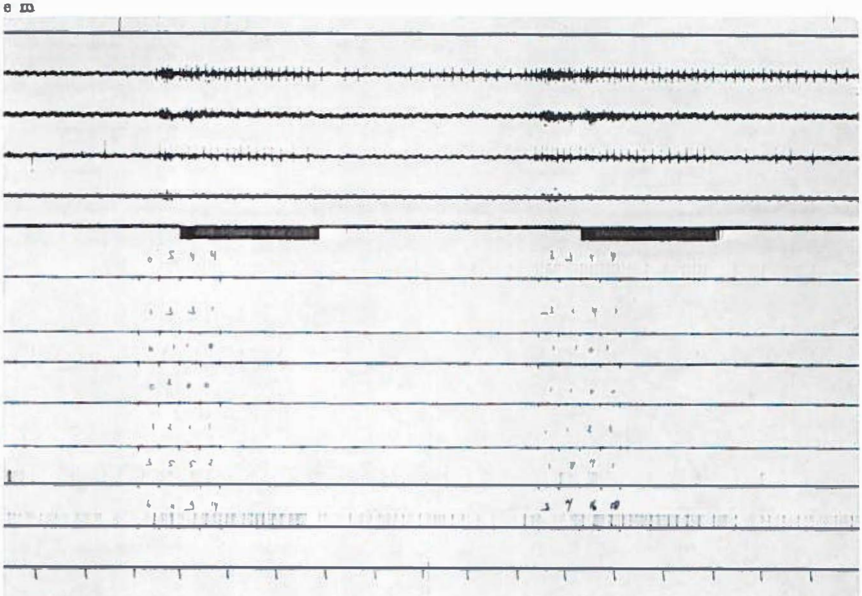


Fig. 26. during /*ɛm:*/.

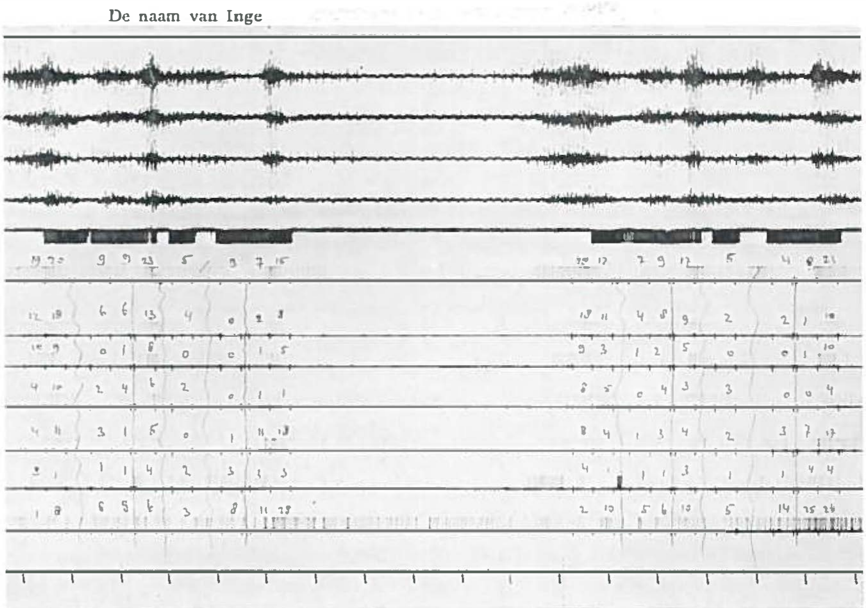


Fig. 27. Electromyographic signals and integrated signal in /*de na:m van iŋə*/.

in 4 time periods of 0.20 sec. were counted, 2 periods of 0.20 sec. preceding the phoneme and 2 periods of 0.20 sec. after the onset of the phoneme.

The same periods of 0.20 sec. were also chosen to evaluate speech in the following way.

kukkuk one time period preceding the first /*k*/ and 2 time periods during production of the first /*u*/ and second /*u*/

pit one time period preceding the /*p*/ and the next period during production of the /*i:*/

pus one time period preceding the /*p*/, the next period during production of the /*u*/, and a following period during production of the /*s*/, which was sustained for a while.

i*ŋə* one time period from the onset of the word, during production of /*i*/, one period during the /*ŋ*/ and one period during the following /*ə*/.

də one time period preceding the onset of the word, the next period during production of /*ə*/.

na: m one time period during production of /*n*/, one period during production of /*a:*/, and one period during production of /*m*/

van one time period during production of /*a*/

iŋə time periods similar to those of the preceding production of /*iŋə*/ were chosen.

The energy display during swallowing was nearly always larger than that during production of phonemes and speech. To compare muscle activity during production of a sustained vowel, the first time period of 0.20 sec. after the onset of each of the vowels was chosen. The muscle activity preceding the sound accounts for the so-called 'ready position' of palate and pharyngeal walls. During the time period preceding the sound, the oropharyngeal structures were set in a 'ready position' for the required sound. To compare muscle activity in the production of plosives, the activity in the time period preceding the sound had to be taken. These plosives were always followed by a vowel. The nasal consonants /*m*/ and /*n*/ were always preceded by the vowel /*ε*/ in this study. To compare the nasal consonants, activity had to be taken after the beginning of the synchronous sound display. In the production of /*kukkuk*/ the difference of activity in the production of a plosive /*k*/ and the vowels /*u*/ was shown. In the production of /*pit*/ and /*pus*/ a similar combination in the production of plosives and vowels was shown. The fricative /*s*/ in /*pus*/ was always sustained for some time periods. In the word /*iŋe*/ there is a combination of vowels and a nasal consonant. In the sample of '*də na: m van iŋə*', there is a combination of 2 nasal consonants and a vowel in the word /*na:m*/. To compare the activity displayed by the different muscles the following procedure was used.

The total number of pulses of the integrated signals was counted for the four time periods of all the chosen vowels and consonants in each muscle lead. The number of pulses of each time period of 0.20 sec. was calculated as a percentage of the total pulse number for the integrated signal of all the isolated test phonemes. The figure of integrated signals of each time period during production of speech was also calculated as a percentage of the total pulse number of the integrated signals during production of the isolated phonemes of the same muscle lead. The percentages of the different muscle leads can be compared. If the total pulse number of the integrated signal was less than 100, then the electrode placement was considered inadequate and not successful. The overall rate of successful placement of electrodes was 75%. The rate of successful placement of electrodes in the different muscles was as follows:

– levator veli palatini	81%
– constrictor pharyngeus superior	73%
– palatoglossus	58%
– palatopharyngeus	78%
– tensor veli palatini	86%

Data of subjects with normal speech

The energy display of the electromyogram varied considerably from one lead to another, up to ten times. The voltages measured ranged from 50 μV up to 500 μV. These inter- and intraindividual voltage differences are caused by variations in the electrodes and their positioning in relation to the active final motor units. During the recording from one muscle lead the maximum voltages usually varied within narrow limits. There was absence of activity in all the muscles during rest and quiet breathing. During speech and swallowing there was a varying degree of activity, usually highest for all muscles during swallowing.

Table 2 Average activity of vowels /*a*/, /*e*/, /*i*/, (0.20 sec. after onset sound), plosives /*pe*/ and /*ka*/, (0.20 sec. before and after onset sound) and nasal sounds /*em*/ and /*en*/, (0.20 sec. after onset sound). Total of percentages for left and right muscle; if only one muscle was measured, then the percentage of this muscle was taken twice.

	Mm. levator					*Mm. constrictor*			
Exp. no.	Vowel	Plosive		Nasal	Score	Vowel	Plosive		Nasal
18	5.5	11.2	4.6	0.9	5	2.9	7.6	6.1	3.9
22	3.8	13.5	4.7	0.4	5	4.7	10.9	8.1	3.6
23	1.9	2.6	5.0	0.7	4	2.1	14.2	17.2	5.9
30	4.0	14.3	8.2	3.5	5	2.9	10.9	7.3	7.4
31	5.0	9.8	6.1	1.5	5	2.8	12.7	5.0	1.2
32	2.7	10.1	4.9	0.4	5	0.3	16.2	10.4	3.2
33	5.2	8.4	6.9	2.2	5	4.3	10.9	11.7	5.0
34	4.0	14.7	4.7	3.2	5	0.7	6.1	11.6	3.0
35						3.8	10.2	20.7	8.6
36	4.4	16.4	12.1	3.0	5	6.6	7.7	17.8	0.9
37	3.3	11.6	7.6	3.0	5	4.2	18.1	16.2	3.4
38	2.2	6.0	7.8	9.7	3	4.0	8.7	6.0	1.5
39	3.8	7.4	5.6	2.6	5	4.6	4.1	5.6	5.5
40	7.8	7.3	16.6	1.8	4				
41	4.4	10.0	6.6	1.3	5	5.5	7.1	6.2	4.4
42	4.6	14.5	7.8	0.8	5	6.0	5.9	5.6	6.5
43	8.0	9.5	4.1	1.0	5	2.7	9.7	8.7	4.1
44	4.0	4.8	5.4	3.2	4	4.4	18.1	9.9	4.9
47	5.1	6.1	5.2	5.6	4	6.6	16.2	8.4	2.2
48	0.6	9.7	6.5	0.3	5	0.7	18.4	3.9	0.7
49	5.4	10.3	11.0	1.9	4	3.6	10.9	7.0	4.3
50	3.6	8.1	6.5	2.6	5	3.6	4.8	7.1	2.7
51	5.6	13.6	5.7	1.7	5				
61	4.8	6.5	4.0	1.4	5	4.3	11.8	10.2	6,6
63	2.4	19.3	9.1	2.8	4	2.0	6.6	19.1	13.7
68	3.9	6.5	3.9	2.0	5	2.8	11.4	12.2	6.9
69	8.3	9.2	6.1	3.3	5	6.1	10.3	8.6	3.3
70	4.0	7.3	4.2	4.5	4				
71	4.2	7.6	7.8	4.3	3	1.0	8.9	4.1	7.4
111	4.3	6.0	6.5	7.6	3	3.3	16.3	15.3	7.5

	Mm. palatoglossus				*M. tensor* (only the right m. tensor was measured in all experiments)			
Exp. no.	Vowel	Plosive		Nasal sound	Vowel	Plosive		Nasal sound
18	1.8	5.9	1.5	5.9	3.3	1.9	3.6	6.3
22					2.2	0.3	1.8	3.1
23					1.7	0.9	2.6	6.4
30	5.0	10.0	12.2	8.2				
31	6.3	8.0	8.4	9.5	2.5	0.2	0.9	7.4
32	0.1	7.4	4.0	6.4	1.9	0.7	2.1	3.6
33	5.3	17.9	10.3	0.3	1.7	2.3	4.1	9.5
34	4.2	14.2	15.7	1.9				
35								
36	6.3	11.3	6.0	7.3	2.9	0.8	3.3	5.0
37	8.9	12.2	2.7	0.9				
38	3.5	12.2	3.1	13.0	0.7	0.2	1.4	15.2
39	3.8	0.8	1.8	11.9	1.5	3.5	2.4	6.6
40	6.0	4.7	17.2	1.7	2.5	4.2	4.2	6.6
41	0.6	4.5	4.5	0.5				
42	2.1	22.4	4.5	1.4	3.7	0.4	2.8	2.6
43					0.6	1.4	5.2	9.7
44	5.1	11.1	6.2	2.1	0.3	0.3	5.1	13.4
47	7.0	9.1	10.4	3.4	0.8	0.8	11.0	2.1
48	6.4	8.4	4.0	4.6	3.4	1.3	2.4	4.3
49					1.4	3.4	6.3	6.1
50								
51	5.4	15.9	9.7	1.2	4,0	1.1	1.8	6.3
Mm. palatopharyngeus					*M. tensor*			
61					1.2	0.1	1.2	3.9
63	2.6	23.6	12.3	2.4	3.2	1.0	2.8	7.9
68	1.4	7.9	3.4	2.1	2.9	0.5	4.4	4.1
69	5.2	8.1	6.7	4.4				
70	7.3	7.8	2.8	1.9	3.0	4.5	1.9	0.6
71	3.9	7.5	6.4	3.7	3.3	2.0	2.0	0.2
111	2.8	13.0	16.4	9.2				

The onset and termination of activity varied between muscles but typical overall patterns of behaviour could be distinguished. The activity of the different muscles can be described according to the percentages in the different muscle leads. The percentages in the different muscle leads for some tests are given in tables (2). The activity in each of the different muscle leads can be described as follows.

Levator veli palatini

The onset of muscle activity usually precedes the sound by 0.20 to 0.40

sec., although longer time periods are often seen when the palate is apparently put into a ready position long before production of a phoneme or speech. The muscle activity during production of vowels varied in the controls, but usually the activity during */a:/*, */o:/* and */e:/* was higher than that during the sustained */i:/* and */y:/*. The activity before the onset of the vowel was usually higher than that during the sustained vowel. The activity during the sustained nasal sounds */m:/* and */n:/* was usually lower than that during the sustained vowels. In 27 of the 30 subjects the activity for the plosives */p/* and */k/* was higher than that for the sustained vowels. In the production of the plosives which were always followed by a vowel */pe:/*, */de:/* and */ka:/*, the activity before the onset of the plosive was usually higher than that in the next time period during the vowel. In 7 individuals this change in activity was reversed. It must be noted that a relatively high activity during the production of nasal sounds was found in these subjects.
In the combination of plosive with vowel during speech as seen in */kukkuk/*, */pit/* and */pus/* the activity of the vowel was usually higher than that before the onset of the preceding plosive. When a vowel was produced in combination with a nasal consonant the muscle activity in the production of the vowel was much lower than that in combination with a plosive. The activity for the nasal consonant was usually lower than that for the vowel, as seen in */iŋə/* and */na:m/* – In a separate table the average activity during the production of the vowels, the plosives */p/* and */k/* and the nasal consonants */m/* and */n/* is shown (table 2).

Constrictor pharyngeus superior

The onset of the constrictor activity was usually a little slower than that of the levator activity, but similar overall patterns in activity could be observed. The variation of the activity of the constrictor was usually larger and less predictable than the variation in levator activity. The constrictor activity during production of a vowel was usually smaller than that in production of a plosive. The activity for the plosive */d/* was usually smaller than that for */p/* and */k/*. The constrictor activity during the production of a nasal consonant was much higher than the levator activity . In many subjects with normal speech, constrictor activity for the nasal consonants, was higher than that for the sustained vowels. In the combination of plosives and vowels, activity during production of the vowels was higher than that in the combination of vowels and nasal consonants.

Palatoglossus

The exact placement of the electrodes in the palatoglossus was much more difficult than in the other muscles (58%). Only 6 of the 22 subjects with normal speech had not been subjected to tonsillectomy. In many of the post tonsillectomy patients there were only remnants of the palatoglossal arch left. In these subjects one must consider the muscles to be severely damaged but they nevertheless had a competent velopharyngeal closure mechanism. However, differences in muscle activity could not be observed in this small group between patients with and those without a previous tonsillectomy. The palatoglossus was usually more active for plosives than for vowels. In the combination of nasal consonants and vowels the palatoglossus was active without measurable differences between the two sounds. During production of isolated nasal consonants there was a varying activity.

Palatopharyngeus

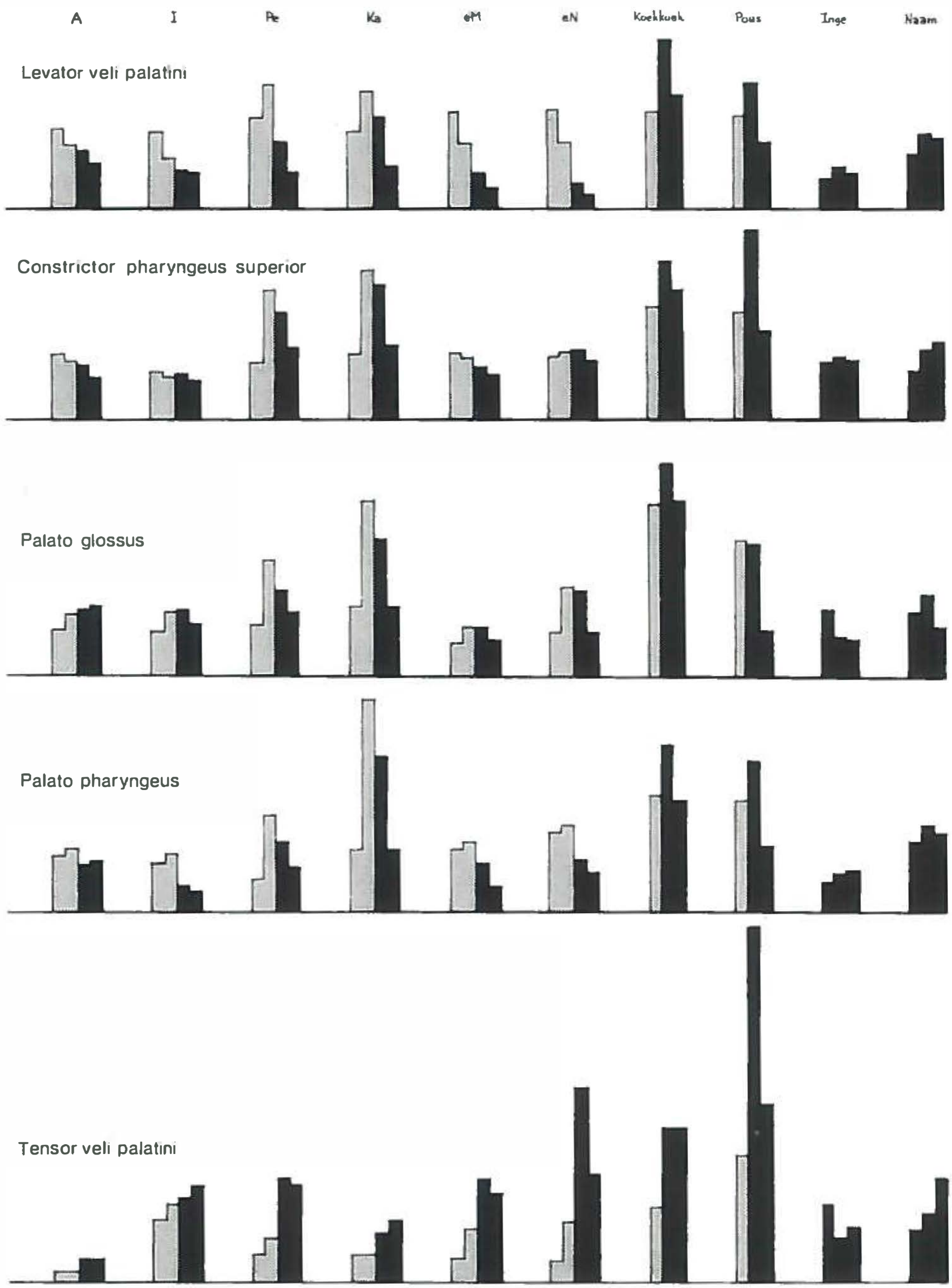
Activity of the palatopharyngeus was studied in 7 people. There was variation in the activity of the different sustained vowels. Usually the activity during the production of */a:/*, */o:/* and */e:/* was higher than that for the vowels */i:/* and */y:/*. There was moderate activity during production of different nasal consonants and vowels without much difference. In the combination of plosive and vowel the activity during the vowel was larger than that for the preceding plosive, as can be seen in */kukkuk/*, */pit/*, and */pus/*.

Tensor veli palatini

Because this muscle plays no active role in speech, it was only measured on the right side. Activity during swallowing was high, as was found for all the other muscles. In many individuals there was a moderate degree of activity in the isolated nasal consonants. There were only small variations in activity during production of isolated phonemes and speech. In the combination of plosive and vowel there was more activity during production of the vowel than before the onset of the preceding plosive, as can be seen in */kukkuk/*, */pit/* and */pus/*.

Conclusion

The activity of the velopharyngeal muscles was always large during swallowing and showed typical variations during production of test phonemes and speech. The muscle activity of the levator was most predictable in the production of different test phonemes and speech. This is in agreement with all previous literature on this subject (chapter 2). The pattern of activity of the levator was more consistent and uniform between the subjects than that of any other of the muscles studied. Yet it must be borne in mind that even in the relatively small group of 30 subjects with normal speech there were some individuals with markedly less variation in activity in plosives and vowels (*//p/*, */d/* and */k/*). Especially these individuals showed more activity during



Comparison of muscle activity according to the average figure of percentages in people with normal speech.

production of nasal sounds (*/m/* and */n/*). A better understanding of the variation in the innervation of the levator, even in subjects with normal speech, is needed. The constrictor was always active during production of the test phonemes and speech.

In tables (table 2) the degree of activity of the different muscles is expressed in percentages in subjects with normal speech during production of the three vowels */a:/*, */e:/* and */i:/*, the plosives */p/* and */k/* and the nasal consonants */m/* and */n/*. The highest activity for all muscles was found during swallowing. In order to compare the relative muscle activities in the patients with those in the controls, a simple grading system can be used when studying the tables. The following criteria as to the degree of muscle activity can be postulated.

Activity of the levator veli palatini

- the average activity for the plosives */p/* and */k/* is higher than the average activity for the vowels */a/:*, */e:/* and */i:/*.
- The average activity for the vowels */a:/*, */e:/* and */i:/* is higher than the average activity for the nasal consonants */m/* and */n/* and activity for the nasals is usually less than 5%.
- The average activity for the plosives */p/* and */k/* is higher than the average activity for the vowel that follows.
- The average activity for the vowels */a:/*, */e:/* and */i:/* is usually between 0.5% and 10%.
- The average activity for the plosives */p/* and */k/* is usually between 2% and 20%.

Activity of the constrictor pharyngeus superior

The average activity for the plosives */p/* and */k/* is higher than the average activity for the vowels */a:/*, */e:/* and */i:/*.
- The average activity for the vowels */a:/*, */e:/* and */i:/* is between 0.5% and 10%.
- The average activity for the plosives */p/* and */k/* is between 5% and 20%.

These criteria were used in a grading system. For every criterium fulfilled, one point was given. When all criteria were fulfilled, 8 points were given.

In the group of subjects with normal speech the following scores were obtained:

68% 8 points
22% 7 points
10% 6 points

The activity of the constrictor in all people fulfilled all the criteria. The activity of the levator did not fulfill all the criteria set. This variability of activity of the levator was mentioned before. The points scored when testing the criteria are given in the same tables in separate columns (table no. 2). It should be borne in mind that no quantification of the energy display in the different muscle leads is given. The percentages show only the variation in the energy display of the electromyographic recordings.

Patients

The activities of the levator and constrictor are most representative of the differences in phonation, as was shown in the preceding section. Electromyographic recordings were made of the levator veli palatini left and right and of the constrictor pharyngeus superior left and right. Recordings of the palatoglossus and tensor veli palatini were made in some patients. In all patients postoperative electromyographic recordings of the pharyngeal flap were made. The variation in activity of the levator veli palatini and the constrictor pharyngeus superior will be analysed in the following descriptive analyses of the activity of the velopharyngeal muscles in patients before and after operation. The criteria described in the preceding section will be used.

Patients before and after operation

Table 3 Average activity of vowels /*a*/, /*e*/, /*i*/, (0.20 sec. after onset sound), plosives /*p*/ and /*k*/, (0.20 sec. before and after onset sound) and nasal sounds /*m*/ and /*n*/, (0.20 sec. after onset sound).
Table of percentages of left and right muscle; if only one muscle was measured, then the percentage of this muscle was taken twice.

I. Cleft palate patients without palate repair

Mm. levator		*Before operation*			
Exp. no.	Vowel	Plosive		Nasal sound	Score
62	1.2	23.8	6.5	0.7	4
64	5.8	8.5	7.9	6.7	3
76					
77	4.1	10.3	9.8	3.9	5
79	8.7	7.6	11.9	4.4	3
78	5.7	11.8	5.9	8.7	3
		After operation			
88	12.2	2.8	3.3	1.2	2
100	5.5	13.5	6.8	5.0	4
106	4.6	9.8	9.3	1.8	5
107	4.3	18.2	8.1	2.1	5
110	6.8	9.6	9.3	6.6	4
108					
90	3.2	8.5	8.8	10.9	2
92	6.5	7.5	3.2	0.2	5

II Cleft palate patients with palate repair and one patient with a submucous cleft palate

Mm. levator	*Before operation*				
Exp. no.	Vowel	Plosive		Nasal sound	Score
53	4.3	17.1	21.9	0.8	4
56	5.6	8.5	5.7	5.5	4
65	3.5	28.5	10.6	1.3	4
72	5.4	8.2	6.3	1.5	5
73	4.8	11.0	8.2	2.2	5
Mm. levator	*After operation*				
82	7.1	8.3	9.3	1.2	4
85	4.4	3.4	4.9	3.5	3
99	7.4	6.1	5.8	0.2	4
101	0.6	10.0	2.7	1.0	4
105	7.3	4.9	5.3	0.2	3
91	6.1	6.5	2.2	0.1	5
94	5.4	9.5	3.9	4.7	5
97	3.1	9.9	13.4	3.4	4
98	5.4	10.4	3.9	1.0	5

III Patients with a congenital short palate

Mm. levator	*Before operation*				
Exp. no.	Vowel	Plosive		Nasal sound	Score
52	5.2	11.0	6.0	14.2	4
54					
57	5.0	7.0	6.4	5.6	3
58					
59	2.6	15.4	10.9	8.3	3
60	3.1	4.3	2.6	1.6	5
66					
74	6.1	15.7	4.6	0.1	5
75	4.8	11.7	7.8	0.8	5
80					
Mm. levator	*After operation*				
81	4.7	11.4	10.9	7.4	3
83	4.2	9.1	6.2	5.2	3
84	5.6	8.6	5.6	0.7	5
87	0	20.4	7.8	4.5	2
86	3.9	12.5	7.4	3.2	5
89	4.4	16.6	12.3	1.8	5
102	3.9	6.5	10.9	7.2	2
103	3.1	21.9	4.4	7.3	2
104	4.2	25.4	6.1	1.3	4
109	1.6	29.7	8.7	4.9	3
45	3.3	8.3	4.4	1.7	5
93	2.8	4.5	6.1	6.3	2
95	5.2	7.6	5.8	3.8	5
96	6.4	8.1	6.8	1.1	5

Patients before and after operation

I. Cleft palate patients without palate repair

Mm. constrictor		*Before operation*				
Exp. no.	Vowel	Plosive		Nasal sound	Score	Score Lev. & Constr.
62	1.0	5.8	1.6	17.5	3	7
64	3.9	13.5	9.2	7.4	3	6
76						
77	2.2	14.3	5.9	2.1	3	8
79	6.6	9.0	14.7	4.4	3	6
78	4.6	7.4	4.7	7.2	3	6
Mm. constrictor		*After operation*				
88						
100	1.4	25.3	6.3	2.7	2	6
106	4.7	7.6	10.1	6.6	2	7
107	2.6	13.5	7.5	1.5	3	8
110	6.2	3.5	8.1	8.0	2	6
108	4.3	6.5	5.1	8.3	3	
90	3.6	7.6	10.5	7.6	3	5
92	0.3	12.7	8.1	6.3	2	7

II. Cleft palate patients with palate repair and one patient with a submucous cleft palate.

Mm. constrictor		*Before operation*				
Exp. no.	Vowel	Plosive		Nasal sound	Score	Score Lev. & Constr.
53	2.6	7.6	15.8	4.3	3	7
56						
65	3.5	9.3	8.7	6.2	3	7
72						
73	0.8	20.6	9.9	7.2	1	6
		After operation				
82	3.8	4.4	14.6	7.7	3	7
85	4.3	5.5	4.5	5.5	3	6
99	5.9	3.5	7.3	2.8	2	6
101						
105	3.1	30.5	9.6	2.5	2	5
91	4.6	17.0	15.8	1.8	3	8
94	3.3	20.9	8.6	4.7	2	7
97	5.9	4.7	7.5	3.2	3	7
98	1.3	5.0	10.4	9.1	3	8

III. Patients with a congenital short palate

Mm. constrictor		*Before operation*				
Exp. no.	Vowel	Plosive		Nasal sound	Score	Score Lev. & Constr.
52	4.6	14.2	9.4	4.8	3	7
54						
57	3.4	6.1	8.4	15.0	3	6
58						
59	1.2	17.1	4.0	16.7	3	6
60						
66						
74	2.9	19.0	9.7	2.1	3	8
75	1.6	9.6	4.9	4.9	3	8
80						
		After operation				
81						
83	2.2	4.6	4.6	3.0	2	5
84						
87						
86	5.7	18.4	6.5	3.8	3	8
89	3.1	9.6	9.0	2.9	3	8
102						
103						
104	3.8	10.6	8.5	8.6	3	7
109	0.9	33.0	16.8	7.7	2	5
45	3.0	8.3	4.4	1.7	3	8
93	5.8	4.8	4.4	0.6	2	4
95	2.4	11.3	9.3	6.2	3	8
96	3.5	15.7	5.8	2.7	3	8

Patients after operation. Average activity of the pharyngeal flap. Table of percentage from one muscle lead

Exp. no.	Vowel	Plosive		Nasal sound	Interval after operation
88	only in swallowing				
100	2.4	15.9	0.9	0.9	
106	only in swallowing				
107	6.5	1.0	1.0	0.5	
110	4.3	3.9	7.3	7.2	
108	only in swallowing				
90	1.3	6.6	5.4	5.5	5 years
92	2.9	8.0	2.8	4.0	4 years
82	1.4	4.9	20.7	1.0	
85	only in swallowing				
99	only in swallowing				
101	neither in swallowing nor in speech				
105	3.3	4.9	3.6	0	
91	only in swallowing				3 years
94	0.4	14.1	3.6	3.6	2 years

97	only in swallowing				5 years
98	3.2	5.5	3.3	0.8	2 years
81	only in swallowing				
83	only in swallowing				
84	only in swallowing				
86	only in swallowing				
87	neither in swallowing nor in speech				
89	only in swallowing				
102	2.1	3.9	4.4	1.2	
103	only in swallowing				
104	only in swallowing				
109	only in swallowing				
45	no muscle lead inserted				1 year
93	0.2	5.3	2.2	0.7	7 years
95	3.6	4.6	2.4	0.8	7 years
96	1.3	10.7	1.4	0.9	7 years

In table (no. 3) the average activities of the levator and constrictor during production of the three vowels, */a:/*, */e:/* and */i:/* the plosives */p/* and */k/* and the nasal consonants */m/* and */n/* are shown. The points scored when testing the criteria in the data on the patients are shown in the same tables.

General findings

In 52 experiments performed in the group of 31 patients, electromyographic recordings from the levator veli palatini and the constrictor pharyngeus superior on both sides were made. In 6 experiments no satisfactory recordings could be made from the levator on either side. In 14 experiments no satisfactory recordings could be made from one of the sides. The placement of electrodes in the levator was successful in 78% of the experiments. In 15 experiments no satisfactory recordings could be made from the constrictor pharyngeus superior on either side. In 14 experiments no satisfactory recordings could be made from one side. The placement of electrodes in the constrictor was successful in 61% of the experiments.

Table 4 Successful placement of electrodes in patients.

			both sides	one side
52 experiments	levator	before operation	12	4
		after operation	20	10
	constrictor	before operation	7	6
		after operation	16	8

With the criteria postulated in the previous section the patients showed the following scores before and after operation. In 36 experiments, electromyographic recordings were made from the levator and constrictor on one or both sides:

Patiënts	Subjects with normal speech
31% – 8 points	68% – 8 points
28% – 7 points	21% – 7 points
28% – 6 points	10% – 6 points
11% – 5 points	
2% – 4 points	

A descriptive analysis of the variation in muscle activity for the patients follows, with a separate section for the activity of the pharyngeal flap, according to tables no. 3.

Eight cleft palate patients without palate repair before operation

In one patient no preoperative recordings were made from the levator or constrictor because the activity during the test phonemes was too small (exp. no. 76). After operation (exp. no. 106) this patient scored 7 points. The preoperative difficulties were probably due to technical imperfections. The patient in exp. no. 62 showed much activity in the production of plosives (23.8) and small percentages in the production of vowels and nasal consonants (vowel 1.2, nasal 0.7) before operation. After operation the same patient (exp. no. 88) failed to meet several criteria and scored only 4 points. The activity of the constrictor usually met the criteria set. In some experiments (79, 110 and 90) the variation of activity was small in the production of vowels, plosives and nasal sounds. These patients may have little variation in the velopharyngeal port opening, and this affects their speech.

Eight cleft palate patients with palate repair and one patient with a submucous cleft palate

In one patient no recordings were made from the constrictor before and after operation (exp. 72, 101). In one patient no recording was made from the constrictor before operation (exp. no. 56). In one patient the variation in the activity of the levator before and after operation and of the constrictor after operation was small (exp. no. 56, 85) in the production of vowels, plosives and nasal sounds.

Fourteen patients with a congenital short palate

In this group the placement of electrodes in the levator and constrictor was less successful. The patients in this group were much younger than those in the other groups. Manipulation and placement of electrodes is difficult in a small oral cavity. In 4 experiments no satisfactory electromyographic recordings could be made from the levator before operation. In 7 experiments electromyographic re-

cordings from one muscle only were taken from the levator after operation. In 5 experiments no satisfactory electromyographic recordings could be made from the constrictor before and after operation. The scores of the levator activity made by the patients who only had postoperative electromyographic recordings were rather low (exp. no. 83, 87, 102 and 109). In the patients tested only postoperatively, rather small variations in muscle activity were usually found (exp. no. 45, 93, 95 and 96).
One patient (exp. no. 74 and 103) showed good variation in levator activity before operation (score 5 points) but much less after operation (score 2 points).

Activity of the pharyngeal flap

Activity was taken from one muscle lead from one side of the flap. Activity of the pharyngeal flap in swallowing was found in all the experiments. In 13 experiments variation of muscle activity during phonation was found. In one patient (exp. no. 105) the activity of the pharyngeal flap seemed to follow that of the levator. Some additional muscle leads placed in this pharyngeal flap revealed the same phenomenon. Except for two experiments (no. 107 and 110), activity of the pharyngeal flap during production of plosives was higher than that during production of vowels or nasal sounds.
In 7 of the 10 patients only tested more than one year after operation activity in the pharyngeal flap was found during phonation. In two patients no activity was found during speech and phonation. In one patient no attempt was made to place an electrode (exp. no. 45). Activity of the pharyngeal flap during phonation was obviously more often present in the patients tested more than one year after the pharyngeal flap operation, as can be seen in table no. 3.

3.2.2.1 Statistical analysis

The group of subjects with normal speech consisted largely of medical students and cannot therefore be regarded as representative of the Dutch population as a whole. The results of this study are gathered from Dutch people speaking their own language but different facts may be gathered from similar studies of other nationalities speaking their own languages.
A comparison of the energy display by electromyographic methods of the various muscles in different subjects can not be made because the positioning of the electrodes in relation to the final motor neuron in the muscles cannot be standardised. Apart from these technical problems it should be kept in mind that the influence of the various muscles in the velopharyngeal mechanism is different because of their anatomical location.
The activity of the velopharyngeal muscles was also studied by a non-para-

* Head Dr. G. J. P. Visser, Department of Surgery, head Prof. Dr. P. J. Kuijjer, State University Hospital Groningen.

metric test. A trend test for related samples was used in this study (De Jonge, 1963).
This statistical analysis was carried out with the aid of Ir. Chaja Idelovici of the Department of Clinical Methodology of our Surgical Clinic.*
The same data of percentages were used as mentioned in the previous section. The results of these tests are given for the various muscles.
In this statistical analysis the following 2 hypotheses were formulated, represented as H0 and H1.

H0: the muscle activity for the various phonemes in the different subjects does not show a similar variation.

H1: the muscle activity in the majority of the subjects is increasing for a specific range of phonemes.

The number of subjects studied is called n. The number of samples (phonemes) is called k. The level of significance is set at 0.05 (5%).
H1 is accepted and the increase in muscle activity is called significant if the probability p is smaller or identical to the level of significance (0.05), H0 is then rejected. When more than 2 phonemes were studied and a significant increase of muscle activity was found and when the increase in muscle activity in the succeeding pairs of phonemes was significant the figure of p is given.
In former studies (van Gelder, 1965, Fritzell, 1969) it was assumed that the elevation of the palate was mainly effected by the degree of levator activity. In the production of a low vowel (*/a/*) the palate would be in a lower position than in the production of a high vowel (*/y/*) which would correspond with a similar variation in levator activity. In the production of nasal sounds (*/m/* and */n/*) levator activity would be smallest and in the production of plosives (*/p/* and */k/*) levator activity would be highest. With this hypothesis an increasing degree of levator activity was to be expected of the phonemes in the following order: nasal — */a:/* — */e:/* — */o:/* — */i:/* — */y:/* — */d/* — */p/* — */k/*
$n = 28$, $k = 9$, $p < 4{,}0 \cdot 10^{-11}$
This is a significant trend of increasing levator activity.
When only the vowels were taken:
$n = 29$, $k = 5$, $p = 0{,}159$.
No significant increase in muscle activity was found. However, when studying the tables differences were noted between the vowels and it was realised that a better order of phonemes with increasing levator activity would be obtained in our material by the average of the percentages obtained for each of the phonemes.
For the vowels the following order was obtained in this manner:
/y:/ — */e:/* — */o:/* — */i:/* — */a:/*
$n = 29$, $k = 5$, $p = 0{,}023$
In this order of phonemes a significant trend of increase in levator activity was present in our material.
However the average of the percentages is influenced more by an extreme figure for one of the experiments than the median of the percentages. For this reason the range of phonemes for each of the muscles was obtained from the median percentage of the muscle activity of the phonemes as found in people with normal speech. The muscle activity of all phonemes was studied ($k = 9$). The muscle activity in production of the vowels only was studied ($k = 5$). The muscle activity of each pair of succeeding phonemes ($k = 2$) obtained from the median percentages of activity was studied beside some other specific pairs. To facilitate comparison of significant increase of muscle activity between the phonemes, a table will be given for each of the 5 muscles studied in subjects with normal speech. In these tables a significant increase of muscle activity is +, no significant increase found is —.

Subjects with normal speech

Levator veli palatini

The following order of phonemes was obtained from the median percentages of muscle activity in which the average percentage from nasal sounds /*m*/ and /*n*/ is referred to as nasal:
nasal — /*y:*/ — /*e:*/ — /*o:*/ — /*i:*/ — /*a:*/ — /*d*/ — /*k*/ — /*p*/, $n = 29, k = 9, p < 4{,}0 \cdot 10^{-11}$.

There is a significant increase in muscle activity. A significant increase was also found for the vowels only.
$n = 29, k = 5, p = 1{,}4 \cdot 10^{-3}$
A significant increase was found in the succeeding pairs of phonemes:
/*y:*/ — /*e:*/ $n = 29, k = 2, p = 0{,}049$
/*a:*/ — /*d*/ $n = 29, k = 2, p = 0{,}049$
/*d*/ — /*k*/ $n = 29, k = 2, p = 5{,}4 \cdot 10^{-3}$
No significant increase was found in the other pairs of succeeding phonemes, but in some other pairs a significant increase was found, which is given in the table.

Levator veli palatini

	nasal	/*y:*/	/*e:*/	/*o:*/	/*i:*/	/*a:*/	/*d*/	/*k*/	/*p*/
nasal		—	+	+	+	+	+	+	+
/*y:*/			+	+	+	+	+	+	+
/*e:*/				—	—	—	+	+	+
/*o:*/					—	—	+	+	+
/*i:*/						—	+	+	+
/*a:*/							+	+	+
/*d*/								+	+
/*k*/									—
/*p*/									

Constrictor pharyngeus superior.

There was a significant increase in muscle activity of the phonemes in the following order.
/*y:*/ — /*i:*/ — /*d*/ — nasal — /*e:*/ — /*a:*/ — /*o:*/ — /*p*/ — /*k*/.
$n = 30, k = 9, p < 4{,}0 \cdot 10^{-11}$
A significant increase was also found for the vowels only.
$n = 30, k = 5, p = 2{,}9 \cdot 10^{-7}$
The findings for each of the pairs of phonemes are given in the table.
A significant increase was found in the succeeding pairs of phonemes:
nasal — /*d*/ $n = 30, k = 2, p = 0{,}035$
/*d*/ — /*p*/ $n = 30, k = 2, p = 1{,}4 \cdot 10^{-3}$

Constrictor pharyngeus superior

	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/	—	+	+	+	+	+	+	+	+
/y:/			—	—	+	+	+	+	+
/e:/				—	—	+	+	+	+
/i:/					—	+	+	+	+
/a:/						—	—	+	+
nasal							+	+	+
/d/								+	+
/p/									—
/k/									

Palatoglossus

There was a significant increase in muscle activity of the phonemes in the following order
/y:/ — */e:/* — */i:/* — nasal — */a:/* — */d/* — */o:/* — */p/* — */k/*
$n = 19, k = 9, p < 4{,}0 \cdot 10^{-11}$
A significant increase was also found for the vowels only.
$n = 19, k = 5, p = 2{,}9 \cdot 10^{-7}$
The findings for each of the pairs of phonemes are given in the table.
A significant increase was only found in the succeeding pairs of phonemes:
/y:/ — */e:/* $n = 19, k = 2, p = 0{,}033$

Palatoglossus

	/y:/	/e:/	/i:/	nasal	/a:/	/d/	/o:/	/p/	/k/
/y:/		+	+	+	+	+	+	+	+
/e:/			—	—	—	+	+	+	+
/i:/				—	—	—	—	+	+
nasal					—	—	—	—	+
/a:/						—	—	+	+
/d/							—	+	+
/o:/								—	+
/p/									—
/k/									

Palatopharyngeus

There was a significant increase in muscle activity of the phonemes in the following order.

/y:/ — */i:/* — */d/* — nasal — */e:/* — */a:/* — */o:/* — */p/* — */k/*
n = 7, k = 9, p = $2{,}9 \cdot 10^{-7}$
A significant increase was also found for the vowels only.
n = 7, k = 5, p = $3{,}2 \cdot 10^{-5}$
The findings for each of the pairs of phonemes are given in the table. No significant increase was found in the succeeding pairs of phonemes.

Palatopharyngeus

	/y:/	*/i:/*	*/d/*	nasal	*/e:/*	*/a:/*	*/o:/*	*/p/*	*/k/*
/y:/		—	—	+	—	+	+	+	+
/i:/			—	+	+	+	+	+	+
/d/				—	—	—	—	—	+
nasal					—	—	+	+	+
/e:/						—	—	—	+
/a:/							—	+	+
/o:/								—	+
/p/									—
/k/									

Tensor veli palatini

There was a significant increase in muscle activity of the phonemes in the following order.
/a:/ — */k/* — */o:/* — */p/* — */e:/* — */y:/* — */d/* — */i:/* — nasal
n = 29, k = 9, p $< 4{,}0 \cdot 10^{-11}$
A significant increase was also found for the vowels.
n = 29, k = 9, p = $9{,}9 \cdot 10^{-10}$
The findings for each of the pairs of phonemes are given in the table.
A significant increase was found in the succeeding pairs of phonemes:
/o:/ — */p/* n = 29, k = 2, p = 0,047
/p/ — */e:/* n = 29, k = 2, p = 0,047
/i:/ — nasal n = 29, k = 2, p = 0,013

Tensor veli palatini

	/a:/	*/k/*	*/o:/*	*/p/*	*/e:/*	*/y:/*	*/d/*	*/i:/*	nasal
/a:/		—	+	+	+	+	+	+	+
/k/			—	+	+	+	+	+	+
/o:/				+	+	+	+	+	+
/p/					+	+	+	+	+
/e:/						—	—	+	+
/y:/							—	+	+
/d/								—	+
/i:/									+
nasal									

To facilitate the comparison of the activities of the different muscles in the production of the various phonemes the following table is given. The figures from 1 to 9 represent the increasing activity of each of the velopharyngeal muscles for the different phonemes.

	nasal	*/y:/*	*/e:/*	*/o:/*	*/i:/*	*/a:/*	*/d/*	*/k/*	*/p/*
Levator	1	2	3	4	5	6	7	8	9
Constrictor	6	2	3	1	4	5	7	9	8
Palatoglossus	4	1	2	7	3	5	6	9	8
Palatopharyngeus	4	1	5	7	2	6	3	9	8
Tensor	9	6	5	3	8	1	7	2	4

In studying this table it should be very clearly realised that these figures do not represent a comparison of the quantity of energy between the various muscles and that variations in muscle activities were not found for many of the phonemes. The trend for increasing muscle activity in the phonemes was only tested in which the figures represent the range number. Highest muscle activity is shown during production of the plosives */p/* and */k/* for all muscles except the tensor. This table clearly shows the balance of muscle activities for the various phonemes. There is no on and off pattern, as these structures are related to each other. The position of the tongue is important and the palatoglossus cannot be regarded merely as an antagonist of the levator, but levator and palatoglossus together widen or narrow the oral cavity, as was also shown by other investigators. (Bell-Berti, 1973 and others).
The tensor has a significant pattern of activity as was shown in the previous section although its influence upon speech is not yet proven by these results.
No significant increase in levator activity was noticed in the elevation of the palate from a low vowel */a:/* to a high vowel */y:/*, yet a significant increase of activity of the tensor at the 1% level of confidence was found between */a:/* and */y:/*.
Fritzell (1969) found more levator activity for the production of the vowels */i/* and */y/* than for the vowels */ae/* and */a/* which findings we could not confirm with our study.
However we found a significant increase in levator activity between the vowels */y:/* and */a:/* as given in the tables.
With the results from our investigation we cannot affirm the hypothesis that levator activity only correlates with elevation of the palate, as far as the vowels are concerned.
The order of vowels in which we found a trend of increasing levator activity does not correlate with the elevation of the palate contrary to the order of vowels originally tested. The varying activity of the palatoglossus beside the elevation of the palate probably declares these findings.
As conclusion we postulate the following hypothesis:

1: The activity of the levator is a function of the elevation of the palate together with the activity of the palatoglossus.
2: The following order of vowels:
/y:/ — /e:/ — /o:/ — /i:/ — /a:/
gives a better representation of the gradually increasing activity of the levator than the order */a:/ — /e:/ — /o:/ — /i:/ — /y:/* which only represents the elevation of the palate.

3: The following order of phonemes:
nasal — /y:/ — /e:/ — /o:/ — /i:/ — /a:/ — /d/ — /k/ — /p/
gives a representation of the gradually increasing activity of the levator muscle.

Patients.

The same order of phonemes was studied as used in the subjects with normal speech for the levator and the constrictor muscles in the patients before and after operation. The range of phonemes in the groups of patients would be different if the median of the percentages was used.

Patients before operation.

Levator veli palatini

A significant increase in muscle activity was found when the same order of phonemes was studied as in the subjects with normal speech.
nasal — /y:/ — /e:/ — /o:/ — /i:/ — /a:/ — /d/ — /k/ — /p/
$n = 16$, $k = 9$, $p = 4{,}0 \cdot 10^{-11}$
Each of the groups of patients was also studied separately and in each group a significant increase in muscle activity was found.
Group I : cleft palate patients without palate repair.
$n = 5$, $k = 9$, $p = 2{,}3 \cdot 10^{-4}$
Group II: cleft palate patients with palate repair and one patient with submucous cleft palate
$n = 6$, $k = 9$, $p = 3{,}4 \cdot 10^{-6}$
Group III: congenital short palate
$n = 6$, $k = 9$, $p = 3{,}4 \cdot 10^{-6}$
When the pairs of each of the succeeding phonemes were studied, a significant increase in muscle activity was only found for /y:/ — /e:/ in group I and II. ($p = 0{,}013$ for both groups) There was a significant decrease of activity between nasal — /y:/ in group I. This finding is at variance with that from the subjects with normal speech.
A significant increase in muscle activity was also found between /i:/ — /a:/ in the cleft palate patients group I and II, (group I $p = 0{,}036$, group II $p = 0{,}013$) and between /y:/ — /a:/ in group II.

Constrictor pharyngeus superior

A significant increase in muscle activity was found when the same order of phonemes was studied as in the subjects with normal speech.
/o:/ — /y:/ — /e:/ — /i:/ — /a:/ — nasal — /d/ — /p/ — /k/
$n = 16$, $k = 9$, $p = 0{,}023$
Each of the groups of patients was also studied separately with the following findings.
Group I: $n = 5$, $k = 9$, $p = 3{,}2 \cdot 10^{-5}$ a significant increase
Group II: $n = 4$, $k = 9$, $p = 0{,}159$ no significant increase
Group III: $n = 7$, $k = 9$, $p = 2{,}9 \cdot 10^{-7}$ a significant increase
The pairs of each of the succeeding phonemes in the different groups were tested. The following succeeding pairs gave a significant increase in muscle activity.

Group I	/i:/ — /a:/	$n = 5$	$p = 0{,}013$
Group II	/a:/ — nasal	$n = 5$	$p = 0{,}023$
	/d/ — /p/	$n = 5$	$p = 0{,}023$
	/p/ — /k/	$n = 5$	$p = 0{,}023$
Group III	/a:/ — nasal	$n = 7$	$p = 0{,}030$
	/d/ — /p/	$n = 7$	$p = 0{,}030$

Before operation

I Levator

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		—	—	—	—	—	—	+	+
/y :/			+	+	—	+	—	+	+
/e :/				—	—	—	—	—	—
/o :/					—	—	—	+	+
/i :/						+	—	+	+
/a :/							—	—	—
/d/								—	—
/k/									—
/p/	n = 5								

After operation

Levator

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		—	—	—	—	+	—	—	+
/y :/			—	—	—	—	—	—	+
/e :/				—	—	—	—	+	+
/o :/					—	—	—	—	—
/i :/						—	—	+	+
/a :/							—	+	+
/d/								—	+
/k/									—
/p/	n = 7								

II

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		—	—	—	—	—	—	+	+
/y :/			+	—	—	+	+	+	+
/e :/				—	—	—	—	+	+
/o :/					—	—	+	+	+
/i :/						+	+	+	+
/a :/							—	+	+
/d/								—	—
/k/									—
/p/	n = 5								

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		+	+	+	—	+	+	+	+
/y :/			—	—	—	—	—	—	—
/a :/				—	—	—	—	—	—
/o :/					—	—	—	—	—
/i :/						—	—	—	—
/a :/							+	—	+
/d/								—	—
/k/									—
/p/	n = 9								

III

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		—	—	—	—	—	+	+	+
/y :/			—	—	—	+	+	+	+
/e :/				—	—	—	+	+	+
/o :/					—	—	+	+	+
/i :/						—	+	+	+
/a :/							—	+	+
/d/								—	+
/k/									—
/p/	n = 6								

	nasal	/y :/	/e :/	/o :/	/i :/	/a :/	/d/	/k/	/p/
nasal		—	—	—	—	—	—	+	+
/y :/			—	+	—	—	—	+	+
/e :/				—	—	—	—	+	+
/o :/					—	—	—	+	+
/i :/						—	—	+	+
/a :/							—	+	+
/d/								+	+
/d/									—
/p/	n = 14								

I Constrictor

	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	—	+	—	—	—	+
/y:/			—	—	+	+	—	+	+
/e:/				—	+	—	—	—	—
/i:/					+	—	—	—	+
/a:/						—	—	—	—
nasal							—	—	—
/d/								—	+
/p/									—
/k/ n = 5									

Constrictor

	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	—	—	—	—	—	—
/y:/			—	—	—	—	—	—	—
/e:/				—	—	—	—	—	—
/i:/					—	—	—	—	—
/a:/						—	—	—	—
nasal							—	—	—
/d/								+	—
/p/									—
/k/ n = 7									

II	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	—	—	+	—	+	+
/y:/			—	—	—	+	—	+	+
/e:/				—	—	+	—	+	+
/i:/					—	—	+	+	+
/a:/						+	+	+	+
nasal							—	—	+
/d/								+	+
/p/									+
/k/ n = 4									

	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	—	—	+	—	+	—
/y:/			—	—	—	+	—	+	—
/e:/				—	—	—	—	+	—
/i:/					+	—	—	—	+
/a:/						—	—	—	—
nasal							—	—	—
/d/								—	—
/p/									—
/k/ n = 9									

III	/o:/	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	+	—	+	+	+	+
/y:/			—	—	—	+	+	+	+
/e:/				—	—	+	+	+	+
/i:/					—	—	+	+	+
/a:/						+	+	+	+
nasal							—	—	—
/d/								+	—
/p/									—
/k/ n = 7									

	/o:	/y:/	/e:/	/i:/	/a:/	nasal	/d/	/p/	/k/
/o:/		—	—	—	—	—	+	+	+
/y:/			—	—	—	—	—	—	—
/e:/				—	—	—	—	+	+
/i:/					—	—	—	+	+
/a:/						—	—	+	+
nasal							—	+	—
/d/								+	+
/p/									—
/k/ n = 13									

Patients after operation

Levator veli palatini

A significant increase in muscle activity was found when the same order of phonemes was studied as in the subjects with normal speech.
nasal — */y:/* — */e:/* — */o:/* — */i:/* — */a:/* — */d/* — */k/* — */p/*
$n = 30$, $k = 9$, $p = 9{,}99 \cdot 10^{-10}$
The increase in muscle activity in each of the groups was also significant.
The pairs of each of the succeeding phonemes in the different groups were tested, in only a few pairs of phonemes was a significant increase observed.
For all groups of patients after operation the muscle activity was significantly increasing in */a:/* — */p/* (group I $n = 7$, $p = 0{,}030$, group II $n = 9$, $p = 0{,}023$, group III $n = 14$, $p = 3{,}7 \cdot 10^{-3}$).
No significant increase was found between */y:/* — */a:/* in each of the groups as was the case in the group of subjects with normal speech and all groups of patients before operation.

Constrictor pharyngeus superior

When the same order of phonemes was studied as in the subjects with normal speech a significant increase in muscle activity was found.
/o:/ — */y:/* — */e:/* — */i:/* — */a:/* — nasal — */d/* — */p/* — */k/*
$n = 29$, $k = 9$, $p = 1.4 \cdot 10^{-3}$.
The increase in muscle activity in each of the groups was also significant. When the pairs of each of the phonemes were studied a significant increase in muscle activity was found only for some of the succeeding pairs in some of the groups of patients after operation.
With this analysis no real differences were found between the muscle activities of levator and constrictor in the groups of patients before and after operation.
The variations in muscle activity were found to be more marked in the cleft palate patients before operation than in the group of patients with a congenital short palate and in the entire group of patients after operation.
As conclusion we postulate the following hypothesis.

1. The trend of increasing activity of the velopharyngeal muscles is present in the same order of phonemes in cleft palate patients, patients with a congenital short palate and in people with normal speech for each of the muscles in their specific order.
2. The differences of activity of the velopharyngeal muscles for each of the two succeeding phonemes are smaller for patients with a cleft palate and a congenital short palate compared to people with normal speech.
3. The trend of increasing activity of the velopharyngeal muscles is present in the same order of phonemes in patients before and after the pharyngeal flap operation.
4. The pharyngeal flap operation does not improve the activity of the velopharyngeal muscles in patients with pronounced differences between the succeeding phonemes.

3.2.3 Speech analysis

Analysis of speech was performed at the Department of Logopedics, University Hospital, Groningen. Speech analysis was performed around the same time as the electromyographic study in the patients subjected to electromyography before and 3 months after operation. People with normal speech were not subjected to speech analysis. In the patients subjected to electromyography more than one year after operation, the latest analysis of speech was chosen. The speech analysis comprised: reading of test sentences, certain vowels, oral and nasal consonants, usually the same as in the electromyographic study. In addition to these tests, conversational speech was analysed. An average grading of these features with regard to nasality was given. The patients subjected to electromyography 3 months after the pharyngeal flap procedure received a more detailed analysis. From all patients, tape recordings were made with the same recording equipment in the same order of test items and by the same specialized speech therapist. These tests were analysed independently by 3 skilled speech therapists on our cleft palate team at the University of Groningen.

The following symbols were used as regards nasality:
normal speech, without nasality = N
rhinolalia aperta, open nasal speech:
slight, moderate, severe = AP1, AP2, AP3
rhinolalia mixta: in some test portions open nasal speech,
in other portions closed nasal speech = M
rhinolalia clausa: closed nasal speech = Cl

In four patients the closing activity of the glottis (glottal stop) was clearly audible during production of speech and oral consonants. Usually the independent judgements of the three evaluators were identical. If the grading was not identical, then that of the majority was accepted. A table of the results is given, which corresponds with the tables dealing with pharyngoscopy and electromyography. The subject numbers correspond with those of the electromyographic experiments. Speech improvement was significant after the operation at the 1% level of significance in each of the groups of patients (trend test, de Jonge, 1963).

In very few patients closed nasal speech resulted after operation, although the separate oral words and vowels appeared to be normal. It is to be noted that this group of patients is not homogeneous, although they are listed together. There are differences in the aetiology of the preoperative rhinolalia aperta apart from the differences in age and in technical performance, i.e. width of the pharyngeal flap in relation to the oropharyngeal port. The results shown in the tables (no. 5) agree with those in earlier and much larger series from our and other cleft palate centres (Huffstadt et al, 1970 and Minami et al., 1975).

The purpose of this study was to compare the speech improvement in relation to the activity of the velopharyngeal muscles (see chapter 1). This relation will be discussed in chapter 4.

Table 5 Tables of speech analysis, before and after operation
speech without nasality or denasality = N
rhinolalia aperta = AP, 1 = slight, 2 = moderate, 3 = severe
rhinolalia mixta = M
rhinolalia clausa = Cl.

I. Cleft palate patients without palate repair

exp.	before operation	age at operation	after operation exp.	speech & reading	oral words	vowels	nasal words nasal consonants
62	AP3	52	88	Cl	N	N	Cl
64	AP3	33	100	M	AP1	AP1	N
76	AP2	34	106	AP2	AP1	AP1	N
77	AP3	39	107	AP2	AP1	AP1	N
79	AP3	50	110	AP2	AP1	AP1	N
78	AP3	46	108	AP2	AP1	AP1	N
		28	90	AP1			
		27	92	N			Cl

II. Cleft palate patients with palate repair and one patient with a submucous cleft palate

exp.	before operation	age at operation	after operation exp.	speech & reading	oral words	vowels	nasal words nasal consonants
53	AP3	22	82	M	AP1	N	N
56	AP3	38	85	AP2	AP1	AP1	N
65	AP3	9	99	Cl	N	N	Cl
72	AP2	9	101	AP2	AP1	AP1	N
73	AP2	14	105	AP1	N	AP1	N
		25	91	AP1			
		14	94	N			
		65	97	AP1			
		19	98	Cl	N	AP1	Cl

III. Patients with a congenital short palate

exp.	before operation	age at operation	after operation exp.	speech & reading	oral words	vowels	nasal words nasal consonants
52	AP2	14	81	N	N	N	Cl
54	AP2	12	83	AP2	AP1	AP1	N
57	AP2	9	84	M	N	N	Cl
58	AP3	12	87	Cl	N	AP1	Cl
59	AP2	7	86	N	N	N	N
60	AP2	15	89	M	N	AP1	N
66	AP1	12	102	AP1	N	N	N
74	AP2	11	103	AP1	AP1	AP1	N
75	AP2	15	104	M	AP1	AP1	Cl
80	AP2	9	109	M	N	AP1	Cl
		27	45	N			
		11	93	Cl	N	N	Cl
		9	95	AP2			
		8	96	AP2			

3.2.4 Sources of error

In planning the investigation, we aimed at objective measurements of the various phenomena in the subjects of the experiments. The group of subjects studied had to be representative of the complete group of individuals within the population. The data recorded through the experiments had to be rated in an identical way throughout the study (Wijvekate, 1972). The number of controls and patients was limited, as it is in any clinical situation. We realized the limitations and shortcomings of our methods of measurements. These limitations will be discussed in separate sections.

Speech analysis.

In our group of patients with an insufficient velopharyngeal mechanism, speech analysis was performed by the Department of Logopedics. Three fully trained speech therapists independently analysed the speech with regard to nasality and articulation, and divided nasality into four grades. These measurements are an interpretation of evaluator judgement. The evaluators are highly qualified, but of course the measurements are not entirely objective.

Pharyngoscopy

With the endoscope, velopharyngeal activity can be observed directly. The movements of the posterior pharyngeal wall, both lateral pharyngeal walls and the soft palate were graded 0 to +++. All the pharyngoscopic measurements were performed by the same investigator, but should still be qualified as subjective.

Electromyographic recording

All the electromyographic recordings were performed by the same investigator with the assistence of a laboratory technician, always using the same instruments.

a. The electrodes were placed in a similar way each time but with individual variations, because human individuals have a similar but not an identical anatomy. In a few instances it was necessary to replace an electrode up to three times in one experiment in order to obtain adequate recordings.
b. The electrodes were not accurate. The distances between the bare tips could vary considerably and the distances between these bipolar electrodes and the motor units were not equal. The voltages recorded from different electrode pairs could vary as much as by a factor 10, although the voltages measured from one pair during one experiment were in the same range and representative of the muscle activity during the experiment.

The 7 electrodes were soldered to a plug in a set order. The signals were fed to pre-amplifiers, from the pre-amplifiers to a tape recorder and to an ink-writing Oscillomink chart recorder. These electromyographic signals were integrated through a separate circuit. In preliminary investigations it was found that, through the performances of these circuits, differences of about 9% in the ultimate data could not be accounted for. The integrated signals were counted by the same investigator and relative percentages of activity of the different muscles in the velopharyngeal mechanism were calculated. In this relatively complicated procedure, mistakes can occur.

4. Discussion of data

4.1 Subjects with normal speech

In this study the subjects with normal speech were subjected only to an electromyographic recording without comparison with pharyngoscopy or speech analysis. In planning the present study electromyographic data on the subjects with normal speech were to be used as control data when studying the electromyographic data on the patients before and after operation. At that time routine pharyngoscopy and speech analysis of the subjects with normal speech was not considered necessary, as Pigott and Boekhoff have presented us with a complete picture. Pharyngoscopy is a routine procedure and is often performed by medical students on themselves by way of instruction. The various degrees of elevation and constriction of the velopharyngeal port during phonation are well known and were already described by Pigott (1969). Skolnick et al. recently demonstrated these variations of elevation and constriction with their advanced radiographic techniques (1970, 1972, 1974). The form and function of the laryngeal, oral and nasal pharynx contribute to speech formation. There is considerable individual variation in the use of the whole vocal tract. The nasal escape is directly related to the velopharyngeal port and to the rate and volume of the air flow which passes through it. The various tests of phonation and speech performed by subjects with normal speech and those performed by patients were certainly not identical . There were always differences in tonality and intensity.
All muscle leads were inserted under direct visual control. This probably accounts for the fact that the positioning of electrodes in the levator and constrictor was fairly successful (levator 81% and constrictor 73%). Fritzell (1969) inserted his electrodes into the levator and constrictor with the aid of a tube catheter through the nasal cavity; his overall rate of successful placement was 69%. The rate of successful placement in the palatoglossus was rather low (58%). The positioning of these electrodes was inaccurate. Tonsils were only present in 6 of our subjects with normal speech. In most of the other people only remnants of the palatoglossal arch or scar tissue were seen.

Our findings agree with those of Fritzell (1969) in most respects. The levator is the most important muscle involved in velopharyngeal closure in normal speech. The variation in the activity of the levator was more consistent and uniform in the individuals tested than the variation in any of the other muscles. The increase in velar height in going from low to high vowels was not reflected in our study by increased levator activity from /*a:*/ to /*y:*/ as Fritzell (1969) showed in a quantitative analysis of 13 individuals. He observed that the velar displacement during vowel production can usually be seen as a relative measure of the degree of levator activity. We observed a significant increase in levator activity together with palatoglossus activity in those vowels in which the oral cavity is expanded, also suggested by Bell-Berti (1973). A significant increase of muscle activity from /*a:*/ to /*y:*/ was observed in the tensor veli palatini. The levator appears to have primary control over the velum if compared with the palatoglossus muscle. However, we found some differences in levator activity in our group of 29 subjects with normal speech as outlined in the preceding chapters. Nine did not meet the criteria of the majority in the group. Six in this group of 9 showed a high levator activity in producing nasal consonants (which is usually found for the constrictor). Sedláčková et al. (1973) found an abnormal innervation of the levator in a group of patients with open nasal speech due to so called 'congenital short palate'. In these patients the dual innervation of the levator by the facial nerve (N.VII) and the vagus nerve (N.X) is unequal. The influence of the facial nerve on the levator is too small and this is reflected in the rapid changes of levator activity required during phonation. Further studies of this variation in the innervation of the levator are required. In the present study we found variations in the activity of the tensor veli palatini most especially during production of nasal consonants. Good muscle activity was usually found during swallowing.

4.2 Patients

Correlations between pharyngoscopy, electromyography and speech analysis

There are certain differences between the groups of patients:
- in rhinolalia before and after operation
- in the structures around the velopharyngeal port
- in scar tissue formation.

To facilitate descriptive analysis, criteria were set for activity of the levator and constrictor in the various tests of phonation. No special criteria were set for the words and test sentences because these would not ensure further differentiation in the activity of levator and constrictor in the patients. Only the variations in the activity of the levator and constrictor were considered, these being the leading muscles of the velopharyngeal mechanism. The variation in levator activity is the most important for evaluation of the velopharyngeal mechanism. The findings obtained from the patients by pharyngoscopy, electromyography and speech analysis were listed in the same order to facilitate comparison.

4.2.1 Cleft palate patients without palate repair

There were 8 patients in this group, ranging in age from 27 to 52 at the time of operation. (mean 38,6 years). This may affect their adaptation of muscle activity to the pharyngeal flap as compared with younger patients.

Six patients were examined before and after operation. Before operation all had worn a speech appliance attached to their dental prosthesis (obturator) and this had partly obstructed the velopharyngeal opening. Postoperatively no obturator was used. All these patients were subjected to palatoraphy combined with a pharyngeal flap in one operation. Two of these patients were only examined after operation. Of the other 6 tested before and after, five had a severe rhinolalia aperta before operation. (AP3). One patient had a moderate rhinolalia aperta (AP2).

In 3 of the 6 patients closure during swallowing was absent before operation. Speech improved in all patients but normal speech and reading was only accomplished by the youngest of this group (exp. no. 92). However even this patient still had a rhinolalia clausa in the nasal words and nasal consonants.

The movements of the posterior pharyngeal wall are usually very small preoperatively, as can be seen at pharyngoscopy. The movements of the lateral pharyngeal walls are due to activity of the constrictor; moderate movements of the posterior pharyngeal wall were seen only in 2 patients (exp. no. 79 and 78).

Closure during phonation was seen only in 3 patients after operation (exp. no. 106, 110 and 92). Two of these patients (exp. no. 106 and 110) showed very little movement of the velum and lateral pharyngeal wall. In view of these findings adequate speech can hardly be expected in such patients. The best speech results were obtained more than one year after operation. These were the younger 2 in this group.

Speech improvement and the scores set by the activity of levator and constrictor muscles, before and after operation, did not show significant correlation. There was however an evident reduction of the movements of the pharyngeal walls after operation with speech improvement. This may well be attributed to scar tissue formation after operation.

4.2.2 Patients with a repaired cleft palate and one patient with a submucous cleft palate

Five patients were examined before and after operation. three of them had severe rhinolalia aperta before operation (Ap3). Four patients were not examined until more than one year after operation. The ages in this group of 9 patients ranged from 9 to 65 years at the time of operation (average 23.8). One patient was 65 years old, one patient was 38 and the others were younger. Only in one pre-operative patient was velopharyngeal closure absent during swallowing. Two patients had moderate rhinolalia aperta before operation (Ap2). Speech improved in all but one of the patients but only one patient achieved 'normal' speech and reading (exp. no. 94).
Complete closure of the velopharyngeal port during phonation was seen in 4 patients (exp. no. 82, 99, 91 and 94). Speech improvement could be expected to be most marked in these patients. Some movement of the posterior pharyngeal wall was seen before operation in all the patients in this group but after operation in only 3 patients. Preoperative and postoperative electromyographic recordings from the levator were made in all patients. In 2 pre-and one postoperative patients no electromyographic recordings could be made from the constrictor due to technical imperfections. No significant correlation was ascertained between the speech improvement after operation and the scores set by the activity of levator and constrictor muscles before and after operation. There was usually some reduction of the movements of the pharyngeal walls after operation, with speech improvement nevertheless.
It is evident however, that after operation closure capacity of the velopharyngeal port is necessary with at least moderate movements of the lateral pharyngeal walls.

4.2.3 Patients with a congenital short palate

Ten patients were tested before and after operation. Four other patients were only tested more than one year after operation. Their ages ranged from 9 to 27 at the time of the operation (average 12.2). One patient was 27, the other patients being between 9 and 15 years old at the time of operation. Only one of the 10 patients tested before operation had severe rhinolalia (AP3, exp. no. 58).
Eight patients tested before operation had moderate rhinolalia (AP2). One patient tested before operation had slight rhinolalia (AP1). Speech improved in all but one of the patients after operation and 3 patients achieved 'normal' speech and reading.
Postoperatively, complete closure of the velopharyngeal port during phonation was seen in 9 patients, but only in one patient preoperatively.

Moderate movements of velum and lateral pharyngeal walls were usually seen in the postoperative patients. Electromyographic recordings for both leads from the levator were unsatisfactory in 4 patients. In 7 patients satisfactory postoperative recordings from the levator were obtained from one muscle lead only. Electromyographic recordings for both leads from the constrictor were unsatisfactory in 5 patients before operation and in the same number after operation.
No significance was ascertained between the speech improvement after the operation and the scores set by the activity of levator and constrictor muscles before and after operation. In this group of patients there was no reduction in the movements of the velopharyngeal wall. The degree of improvement of speech varied in different patients. In 2 patients (exp. no. 95 and 96) examined 7 years after operation, the mobility of the pharyngeal walls was good, together with the activity of levator and constrictor muscles, the speech however was rhinolalia aperta (AP2). These patients were operated upon at the age of 9 and 8 years. These 2 patients clearly show that mobility of the pharyngeal walls and good muscle activity are not enough to gain adequate speech. The co-ordination of these structures has to be well established for such speech.

4.3 Activity of the pharyngeal flap

In 13 patients the pharyngeal flap showed some variation in activity (42% of all postoperative patients). However there was no relation between the muscle activity of the pharyngeal flap and the closure capacity in phonation or speech improvement in these patients.

This descriptive analysis clearly shows the many differences in age and in quality of preoperative speech and the range of speech improvement gained by the operation. Only the variation in muscle activity of levator and constrictor were compared in the different patients, the variations in levator activity being especially important for the quality of speech. The scar formation from the pharyngeal flap operation affected the free movements of the velopharyngeal structures and reduced the changes in the opening of the velopharyngeal port which are necessary for normal speech.

In order to facilitate comparison between the results of the different tests, a simple grading system was set up for pharyngoscopic examination and speech analysis. The movements of the soft palate, and the lateral and posterior pharyngeal walls have already been shown in table 1 expressed in 4 grades from — to +++ for large movements of the corresponding structures. The following points can be given:

— = 0 points
+ = 1 point
++ = 2 points
+++ = 3 points

A maximum of 9 points can be scored for the movements of the soft palate, the lateral and posterior pharyngeal walls. A similar grading system was developed for the speech analysis as follows:

rhinolalia aperta (severe)	AP3 = 1 point
rhinolalia aperta (moderate)	AP2 = 2 points
rhinolalia aperta (slight)	AP1 = 3 points
rhinolalia mixta	M = 4 points
rhinolalia clausa	Cl = 5 points
normal speech	N = 6 points

With these grading systems for pharyngoscopic analysis, speech analysis and electromyographic recordings, the best results are expressed in the highest scores. Tables (6) are presented for better comparison between the data obtained by speech analysis, electromyographic recordings of muscle activity and nasopharyngoscopic examination of the velopharyngeal port.

Table 6 Comparison of speech analysis, muscle activity by electromyographic recordings and movements of the velopharyngeal walls by nasopharyngoscopic examination.

I. Cleft palate patients, without palate repair

exp.	pharyngoscopy	speech analysis	EMG score lev. + constr.	lev.
		Before operation		
62	6	1	7	4
64	4	1	6	3
76	3	2		
77	3	1	8	5
79	6	1	6	3
78	6	1	6	3
		After operation		
88	4	5		2
100	3	4	6	4
106	2	2	7	5
107	3	2	8	5
110	2	2	6	4
108	3	2		
90	4	3	5	2
92	4	6	7	5

II. Cleft palate patients with palate repair and one patient with a submucous cleft palate

		Before operation		
exp.	pharyngoscopy	speech analysis	EMG score lev. + constr.	lev.
53	5	1	7	4
56	5	1		4
65	4	1	7	4
72	5	2		5
73	5	2	6	5
		After operation		
82	4	4	7	4
85	4	2	6	3
99	5	5	6	4
101	5	2		4
105	2	3	5	3
91	5	3	8	5
94	5	6	7	5
97	2	3	7	4
98	3	5	8	5

III. Patients with a congenital short palate

		Before operation		
exp.	pharyngoscopy	speech analysis	EMG score lev. + constr.	lev.
52	3	2	7	4
54	4	2		
57	2	2	6	3
58	2	1		
59	2	2	6	3
60	4	2		5
66	4	3		
74	5	2	8	5
75	3	2	8	5
80	4	2		
		After operation		
81	4	6		3
83	4	2	5	3
84	3	4		5
87	5	5		2
86	4	6	8	5
89	4	4	8	5
102	4	3		2
103	4	3		2
104	5	4	7	4
109	6	4	5	3
45	3	6	8	5
93	3	5	4	2
95	4	2	8	5
96	5	2	8	5

5. Conclusions

The purpose of this study was expressed in five questions. The results are given as answers to these questions.

5.1 How are the activities of the velopharyngeal muscles related in subjects with normal speech?

The relations of some of the muscles of the velopharyngeal mechanism have already been discussed by several others (see chapter 2). The activity of the muscles of the velopharyngeal mechanism was always high during swallowing and showed a typical variation during production of test phonemes and speech. The levator showed a more consistent and uniform activity pattern in the subjects than any other muscle. The activity of the levator for the plosives was significantly higher than for the sustained vowels. The activity for nasal sounds was significantly smaller than for the vowels and plosives. In a small group of subjects with normal speech, levator activity had a different pattern with relatively more activity in nasal sounds.
The constrictor pharyngeus superior was always active in the production of test phonemes and speech with a pattern resembling that of the levator but usually with more activity for nasal sounds. The palatoglossus and levator together enlarge or narrow the oral cavity and both influence the palatal elevation. The palatopharyngeus usually showed more activity during nasal consonants and plosives than in the different vowels, although the variations were small. The tensor veli palatini showed only small variations during speech, being most active during the nasal sounds.

5.2 What are the causes of velopharyngeal incompetence in patients with
a. congenital short palate
b. cleft palate?

In patients with a congenital short palate the speech produced was usually slight to moderate rhinolalia aperta (AP1, AP2). The velopharyngeal structures were unable to produce closure during phonation,

although closure in swallowing was always readily established. In many patients the velopharyngeal port during rest was considerably larger than in subjects with normal speech. Yet in some of the patients the movements of the velum were markedly smaller than in subjects with normal speech. The variation of levator activity during speech in many of these patients was less than in subjects with normal speech. These findings are similar to those of Sedláčková (1973) who demonstrated the dual innervation of the levator veli palatini by the facial and the vagus nerves. In patients with a congenital short palate the innervation of the levator by the facial nerve is impaired.
In patients with a cleft palate, the opening between oral and nasal pharynx was too large, yet closure during swallowing could be achieved in some patients by good constrictive activity of lateral and posterior pharyngeal walls. In patients with a cleft palate who had undergone palatoraphy and still had rhinolalia, the movements of the velopharyngeal walls were obviously insufficient or the velopharyngeal gap was too large. This was partly caused by the scar tissue in the operated palate. The variations in activity of the levator and constrictor are usually fair but rarely as good as those in the majority of the subjects with normal speech.

5.3 How are the activities of the velopharyngeal muscles related in patients with rhinolalia aperta?

In a descriptive analysis the variations in activity of the levator and constrictor in most patients were less than in the subjects with normal speech. The activity of the levator in particular does not follow the normal pattern in some of the patients with a congenital short palate, which is compensated by good constrictive activity.

5.4 a. How are the activities of the velopharyngeal muscles related in patients treated with an inferiorly based pharyngeal flap?

The variations in activity of levator and constrictor usually did not alter very much in patients before and after operation. The movements of the velopharyngeal walls however, were certainly affected by the pharyngeal flap itself and by scar tissue from the operation. These differences were usually observed at pharyngoscopy. The levator retained its usual variations and its influences on the movements of the anterior part of the lateral pharyngeal walls.

b. Is the inferiorly based pharyngeal flap itself active?

The pharyngeal flap itself was active during phonation although apparently this had little significance in speech.

5.5 Can activity of the velopharyngeal muscles be used as a predictor of speech improvement when operation is considered?

It is not only the presence of activity that counts, but also the pattern of variation in the activity during phonation. In patients who have a normal pattern of variation in activity of levator and constrictor, speech improvement can be expected with an adequate velopharyngeal flap. However, the amplitudes of the movements of the velopharyngeal structures were usually less than those in subjects with normal speech. When the pattern of variation in levator and constrictor activity is not distributed properly before operation, normal speech cannot be expected after operation.

In this study the activities of the velopharyngeal muscles in subjects with normal speech were examined in relation to each other. The activities of the levator and constrictor of patients before and after operation were compared with those in the subjects with normal speech. Comparison of the activities of the different muscles can only be made as a comparison of the patterns of variation of the different muscle signals. In subjects with normal speech we found different patterns of variation in activity of levator and constrictor which were not described before in an electromyographic study. These findings agree with those obtained by Skolnick et al. (1971, 1972, 1974 and 1975) in a radiological study of the velopharyngeal area.
More studies on the dual innervation of the levator, even in subjects with normal speech are needed. The patterns of variation of levator activity in patients before and after operation usually differed from those in the majority of subjects with normal speech. The movements of the velopharyngeal walls in the postoperative patients were often of insufficient amplitude to give normal speech, but speech improvement was achieved by operation. We were able to make satisfactory electromyographic recordings without disturbing speech, using the oral approach to insert the thin bipolar wire electrodes. This method can be used for further investigation of the velopharyngeal muscles and their relation to speech and to Eustachian tube function in patients with various conditions.

6. Summary

This study was presented in two parts:
1. electromyography of the velopharyngeal mechanism in subjects with normal speech.
2. electromyography, pharyngoscopy and speech analysis in patients with open nasal speech.

In recent years two carefully designed electromyographic studies on velopharyngeal function in people with normal speech were published by Fritzell (1963, 1969). Recent developments in electromyographic techniques and data recording made a new study worthwhile.

Transnasal pharyngoscopy is a routine method of examination of the velopharyngeal mechanism in our department.

In planning the present study the following questions were raised:
1. How are the activities of the velopharyngeal muscles related in subjects with normal speech?
2. What are the causes of velopharyngeal incompetence in patients with a. congenital short palate
   b. cleft palate?
3. How are the activities of the velopharygneal muscles related in patients with rhinolalia aperta?
4. How are the activities of the velopharyngeal muscles related in patients treated with an inferiorly based pharyngeal flap?
5. Can activity of the velopharyngeal muscles be used as a predictor of speech improvement when operation is considered?

The following muscles were examined in a series of 29 adult subjects with normal speech:

levator veli palatini
tensor veli palatini
constrictor pharyngeus superior

The palatoglossus and palatopharyngeus were examined in some of the subjects with normal speech. This series clearly shows that the constricting activity of the constrictor pharyngeus superior plays an important and varying role in the velopharyngeal closure mechanism during speech. The valve-like action of the soft palate is largely controlled by the levator veli palatini. The levator veli palatini is the

leading muscle in control of the velopharyngeal mechanism in speech. In this study we found different patterns of variation in activity of levator and constrictor in subjects with normal speech, which had not been described before in an electromyographic study. These findings agree with those obtained by Skolnick et al. (1970, 1972, 1974, 1975) in a radiological study of the velopharyngeal mechanism. In a series of 21 patients with rhinolalia aperta (open nasal speech) the activity of the levator and constrictor muscles were investigated. These patients were treated with an inferiorly based pharyngeal flap. In this procedure a bridge is formed by transplanted tissue from the posterior pharyngeal wall to the margin of the soft palate according to Rosenthal (1924). In this way a living obturator is formed which has been shown to give marked speech improvement in a large group of patients with rhinolalia aperta.
A series of 10 patients who were operated on more than one year earlier was also studied. Pharyngoscopy and speech analysis was performed in all patients. The patterns of variation in levator activity in patients before and after operation usually differed from those in the majority of the subjects with normal speech. The movements of the velopharyngeal walls in the postoperative patients were often insufficient to produce normal speech but speech improvement was gained by the operation. The pharyngeal flap itself was usually only active during swallowing.
We were able to make satisfactory electromyographic recordings without disturbing speech using the oral approach to insert thin bipolar wire electrodes. This method can be used for further investigation of the velopharyngeal muscles and their relation to speech and to Eustachian tube function in patients with various conditions.

Samenvatting

Het onderzoek bestaat uit twee delen.
1. Electromyografie van de spieren die betrokken zijn bij het velopharyngeale afsluitmechanisme bij mensen met een ongestoorde spraak. Het velopharyngeale afsluitmechanisme zorgt voor een gehele of gedeeltelijke afsluiting van de neusholte ten opzichte van de mondholte zoals dat noodzakelijk is bij slikken, blazen, zuigen en tijdens het spreken.

2. Electromyografie, nasale pharyngoscopie en een spraakbeoordeling van patienten met open neusspraak. (rhinolalia aperta).

De afgelopen jaren heeft Fritzell (1963, 1969) 2 zorgvuldig uitgevoerde onderzoekingen gepubliceerd, waarbij met behulp van electromyografie de velopharyngeale afsluiting bij een groep mensen met ongestoorde spraak werd onderzocht.
De technische ontwikkeling van de electromyografische onderzoekmethoden en de verwerking van de verkregen gegevens waren de aanleiding tot een volgend onderzoek.
De transnasale pharyngoscopie is een gemakkelijk bruikbare onderzoekmethode van het velopharyngeale afsluitmechanisme.
Dit onderzoek wordt op onze afdeling plastische chirurgie te Groningen reeds enkele jaren geregeld uitgevoerd.

De vraagstelling werd als volgt geformuleerd.
1. Hoe is de verhouding van de activiteiten van de velopharyngeale spieren bij mensen met een ongestoorde spraak?
2. Wat zijn de redenen voor een velopharyngeale insufficientie bij patienten met een:
   a. congenitaal te kort palatum,
   b. gespleten gehemelte?
3. Hoe is de verhouding van de activiteiten van de velopharyngeale spieren bij patienten met een rhinolalia aperta?
4. Hoe is de verhouding van de activiteiten van de velopharyngeale spieren bij patienten met een caudaal gesteelde pharynxlap?

Bij deze patienten werd met behulp van een strook weefsel (slijmvlies + spierlaag) uit de achterste keelwand een brug gemaakt tussen de achterste keelwand en het gehemelte.
De grote opening tussen mond en neusholte wordt op deze manier verdeeld in 2 kleine openingen die gemakkelijker kunnen worden afgesloten door bewegingen van de wanden van de neus-keelholte.
5. Is het mogelijk naar de aard van de activiteiten van de velopharyngeale spieren een voorspelling te doen over de spraakverbetering indien een operatie wordt overwogen?

De volgende spieren werden onderzocht bij 29 mensen met een ongestoorde spraak:

levator veli palatini
tensor veli palatini
constrictor pharyngeus superior
palatoglossus
palatopharyngeus.

De laatste twee spieren werden slechts bij een deel van de mensen onderzocht.
Met dit onderzoek werd aangetoond dat de constrictor pharyngeus superior een belangrijke en wisselende functie heeft bij het velopharyngeale afsluitmechanisme.
De bewegingen van het gehemelte worden grotendeels bestuurd door de levator veli palatini.
De levator heeft de meest uitgesproken en voorspelbare wisselingen in activiteit van de spieren van het velopharyngeale afsluitmechanisme tijdens de spraak.
In deze groep mensen met een ongestoorde spraak was er een duidelijk individueel verschil in activiteit van de levator en constrictor. Bij een klein aantal mensen met een ongestoorde spraak waren de bewegingen van de achterste keelwand + zijwanden door activiteit van de constrictor veel duidelijker dan bij de anderen.
Deze bevindingen door middel van electromyografie verkregen bevestigen de resultaten zoals Skolnick en medewerkers (1970, 1972, 1974, 1975) dit ook in een radiologisch onderzoek aantoonden.
Bij 21 patienten met een rhinolalia aperta (open neusspraak) werden de activiteit van de levator en constrictor onderzocht voor en na de operatie, waarbij een pharynxplastiek werd verricht (aanbrengen van een pharynxlap).
Deze patienten werden voor de operatie en 3 maanden na de operatie onderzocht.
Tien andere patienten die reeds meer dan 1 jaar tevoren waren geopereerd werden ook onderzocht.
Bij alle patienten werd naast de electromyografie ook nasale pharyngoscopie en uitgebreid spraakonderzoek verricht.

De activiteit van de levator bij de verschillende groepen patienten (a. congenitaal te kort palatum en b. patienten met een gespleten gehemelte) voor en na operatie was anders dan bij de meerderheid van de mensen met een ongestoorde spraak.
Bij de geopereerde patiënten waren de bewegingen van de wanden van de neus-keelholte en pharynxlap vaak onvoldoende om geheel normale spraak te bereiken. Na de operatie werd altijd een duidelijke spraakverbetering gevonden. De pharynxlap was duidelijk actief tijdens het slikken bij alle patiënten en soms ook tijdens de spraak zoals met behulp van electromyografie kon worden aangetoond.
Met behulp van de door ons gebruikte methode waarbij wij via de mond dunne (0.05 mm) bipolaire draadelectroden inbrachten werden betrouwbare electromyogrammen verkregen zonder de spraak te storen. Op deze wijze kan verder onderzoek naar de activiteit van de spieren rond het velopharyngeale afsluitmechanisme worden verricht en ook naar de invloed van deze spieractiviteit op de buis van Eustachius.

Résumé

Le mécanisme de fermeture vélo-pharyngien peut isoler partiellement ou totalement les fosses nasales de la cavité buccale, selon les besoins, dans des situations aussi différentes qu'avaler, souffler, sucer et parler. Les recherches effectuées comprennent deux parties:
1. L'électromyographie des muscles qui jouent un rôle dans le mécanisme vélo-pharyngien chez les sujets à élocution normale.
2. L'électromyographie, la pharyngoscopie nasale et l'examen orthophonique chez des sujets souffrant de rhinolalie ouverte.

En 1963 et 1969 Fritzell a publié deux rapports sur des recherches soigneusement exécutées au cours desquelles il a examiné le mécanisme vélo-pharyngien chez un groupe de sujets à élocution normale en se servant de l'électromyographie.
Le progrès des techniques de recherches électromyographiques et de l'interprétation des enregistrements ont suscité de nouvelles recherches. La pharyngoscopie transnasale est une méthode facilement applicable pour l'étude du mécanisme vélo-pharyngien; dans le service de chirurgie plastique de Groningue, elle est régulièrement appliquée depuis plusieurs années.

En préparant cette recherche les problèmes posés furent les suivants:
1. Quelles sont les relations entre les diverses activités des muscles vélo-pharyngiens chez des sujets à élocution normale?
2. Quelles sont les causes d'une insuffisance vélo-pharyngienne chez les sujets souffrant:
a. de brièveté congénitale du voile,
b. d'une fente palatine?
3. Quelles sont les relations entre les diverses activités des muscles vélo-pharyngiens chez les sujets souffrant de rhinolalie ouverte?
4. Quelles sont les relations entre les diverses activités des muscles vélo-pharyngiens chez les sujets traités avec un lambeau pharyngien à base inférieure? Chez ces malades un pont a été construit entre la paroi postérieure du pharynx et la marge du voile du palais en se servant d'une bande de tissu musculo-muqueux prélevée sur cette

paroi postérieure du pharynx selon la méthode Rosenthal (1924) Ainsi la grande ouverture primitive entre la cavité buccale et les fosses nasales est divisée en deux petites ouvertures qui peuvent être obturées plus facilement par les mouvements des parois pharyngiennes

5. Est-il possible de prévoir une amélioration de l'élocution en se basant sur les caractéristiques des activités des muscles vélo-pharyngiens quand il est question d'une intervention chirurgicale? Dans une série de 29 adultes à élocution normale, l'enregistrement a porté sur les muscles suivants:

- le péristaphylin interne
- le péristaphylin externe
- le constricteur supérieur de pharynx
- le glosso-staphylin
- le pharyngo-staphylin.

Ces deux derniers muscles ne furent étudiés que chez une partie des sujets à élocution normale.

Les recherches ont révélé une fonction importante et variable du constricteur supérieur du pharynx dans le mécanisme vélo-pharyngien durant l'élocution. La fonction de clapet du voile du palais est en majeure partie dirigée par le péristaphylin interne. Ce muscle en activité a les variations les plus prononcées et les plus prévisibles de tous les muscles du mécanisme vélo-pharyngien pendant l'élocution.
Dans le groupe des sujets à élocution normale, il y avait des différences individuelles manifestes du péristaphylin interne et du constricteur, ce que n'avaient pas décrit les études électromyographiques antérieures. Ces résultats confirment les résultats obtenus par Skolnick et col. (1970, 1972, 1974, 1975) dans une étude radiologique du mécanisme vélo-pharyngien.
Chez 21 sujets souffrant de rhinolalie ouverte, l'activité des muscles péristaphylin interne et constricteur supérieur du pharynx a été étudiée avant et trois mois après la pharyngoplastie (application d'un lambeau de la paroi postérieure du pharynx sur le voile du palais).
Un autre groupe de 10 sujets qui avaient été opérés plus d'un an auparavant a aussi été étudié.
En plus de l'électromyographie, une pharyngoscopie et un examen orthophonique détaillé ont été pratiqués chez tous les malades.

L'activité du péristaphylin interne chez les différents groupes de malades (a. brièveté congénitale du voile, b. fente palatine) avant et après intervention était différente de celle de la majorité des sujets à élocution normale.
Chez les sujets opérés, les mouvements des parois vélo-pharyngiennes et du lambeau pharyngien étaient souvent insuffisants pour arriver à

une élocution parfaitement normale; l'élocution toutefois s'améliorait après l'opération. Chez tous les malades le lambeau pharyngien avait une activité distincte pendant la déglutition et parfois aussi pendant l'élocution, ce qu'a pu démontrer l'électromyographie.

Nous avons pu avoir des données précises d'électromyographie sans troubles d'élocution en introduisant oralement des électrodes bipolaires très fines, d'un diamètre de 0,05 mm. Cette méthode permet des recherches ultérieures sur l'activité des muscles dans le mécanisme vélo-pharyngien et aussi de leur influence sur le fonctionnement de la trompe d'Eustache.

Zusammenfassung

Das Untersuchungsverfahren besteht aus zwei Teilen.

1. Elektromyographie der Muskeln in bezug auf den velopharyngealen Abschlußmechanismus bei Patienten mit Sprechstörnissen.
   Der velopharyngeale Abschlußmechanismus bewirkt einen vollständigen oder nur geringfügigen Abschluß der Nasenhöhle hinsichtlich der Mundhöhle, wie es beim Schlucken, Blasen, Saugen, Lutschen und Sprechen notwendig ist.
2. Elektromyographie, nasale Pharyngoskopie und eine Sprechbeurteilung der Patienten mit einer offenen näselnden Sprechart.

In den vergangenen Jahren (1963, 1969) hat Fritzell zwei sorgfältig ausgeführte Untersuchungen veröffentlicht, indenen mit Hilfe der Elektromyographie der velopharyngeale Abslußmechanismus geprüft wurde.
Die technische Entwicklung der elektromyographischen Untersuchungsverfahren und die Datenverarbeitung veranlaßten eine weitere Untersuchung.
Die transnasale pharyngoskopie ist eine einfache Untersuchungsmethode des velopharyngealen Abschlußmechanismus.
Diese Untersuchung wird in unserer Abteilung plastischer Chirurgie in Groningen schon seit einigen Jahren regelmäßig durchgeführt.

Die Fragestellung wurde folgendermaßen formuliert:
1. Wie ist das Verhältnis der Wirkungen der velopharyngealen Muskeln bei sprachlich Unbehinderten?
2. Welche sind die Gründe für eine velopharyngeale Insuffizienz bei Patienten mit einem:
   a. kongenital zu kurzen Palatum
   b. einem gespaltenen Gaumen (einer Palatoschizis)?
3. Wie ist das Verhältnis der Wirkungen der velopharyngealen Muskeln bei Patienten mit einer Rhinolalia aperta?
4. Wie ist das Verhältnis der Wirkungen der velopharyngealen Muskeln bei Patienten mit einem kaudal gestielten Pharynxlappen?

Bei diesen Patienten wurde mittels eines Gewebestreifens (Schleimhaut + Muskelschicht) aus dem hinteren Gaumensegel und dem Gaumen eine Brücke zwischen dem hinteren Gaumensegel und dem Gaumen konstruiert. Die große Öffnung zwischen Mund- und Nasenhöhle wird auf diese Weise verteilt in zwei kleine Öffnungen, die durch Schwingungen der Wände von der Nasen- und Rachenhöhle abgeschlossen werden können.

5. Ist es möglich je nachdem die Wirkungen der velopharyngealen Muskeln eine Prognose über die Sprechverbesserung zu geben, wenn eine Operation in Betracht gezogen wird.

Folgende Muskeln wurden bei 30 Sprech-ungestörten geprüft
- levator veli palatini
- tensor veli palatini
- constrictor pharyngeus superior
- palatoglossus
- palatopharyngeus.

Die letzten zwei Muskeln wurden nur bei einem Teil der Versuchspersonen kontrolliert.
Bei dieser Untersuchung zeigte sich, daß der constrictor pharyngeus superior eine wichtige und wechselnde Funktion beim velopharyngealen Abschlußmechanismus hat.
Die Bewegungen des Gaumens werden zum größten Teil durch den levator veli palatini gesteuert. Der levator hat die ausgeprägtesten und prognostizierendsten Schwankungen in der Muskelwirkung des velopharyngealen Abschlußmechanismus während des Sprechens.
In dieser Gruppe sprech-ungestörter Verschuchspersonen lag ein deutlicher individueller Unterschied vor in der Wirkung des levator und constrictor.
Bei einer kleineren Anzahl sprech-ungestörter Versuchspersonen waren die Schwingungen der hinteren Gaumensegelwand und Seitenwände durch die Wirkung des constrictor deutlicher spürbar als bei den anderen.
Diese Ergebnisse durch Elektromyographie bestätigen die Resultate wie Skolnick und seine Mitarbeiter (1971, 1972, 1974, 1975) dies auch in einer radiologischen Untersuchung nachwiesen.
Bei 21 Patienten mit einer Rhinolalia aperta, bei denen eine Pharynxplastik vorgenommen wurde, wurde die Wirkung des levator und constrictor geprüft vor und nach der Operation. Diese Patienten wurden vor und drei Monate nach der Operation untersucht. Weiter wurden auch 10 andere Patienten untersucht die schon vor mehr als einem Jahr operiert worden waren. Bei allen Patienten wurde neben der Elektromyographie auch nasale Pharyngoskopie und eine eingehende Sprechuntersuchung durchgeführt.
Die Wirkung des levator bei den verschiedenen Gruppen von Patienten

(a. mit kongenital zu kurzen Palatum, b. mit gespaltenem Gaumen) vor und nach der Operation war verschiedenartiger als bei der Mehrzahl der sprech-ungestörten Versuchspersonen.
Bei den operierten Patienten waren die Schwingungen der Nasen-Rachenhöhlenwände und des Pharynxlappens oft unzureichend für ein ganz normales Sprechen. Nach der Operation konnte man immer eine bedeutende Besserung der Sprechfähigkeit konstatieren. Bei allen Patienten war der Pharynxlappen offensichtlich tätig beim Schlucken und gelegentlich auch beim Sprechen, wie es sich durch die Elektromyographie zeigen ließ.
Mit Hilfe der von uns angewandte Methode, mit der wir in den Mund dünne (0.05 mm) bipoläre Drahtelektroden hineinführten, wurden zuverlässige Elektromyogrammen erhalten ohne daß das Sprechen beeinträchtigt wurde.
Auf diese Weise kann eine weitere Untersuchung nach der Wirkung der Muskeln von dem velopharyngealen Abschlußmechanismus und auch nach der Einwirkung dieser Muskeln auf die Eustachische Röhre durchgeführt werden.

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